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GLOBAL ENVIRONMENTAL CHANGE RESEARCH

HEARING

BEFORE THE

SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE

AND THE

NATIONAL OCEAN POLICY STUDY

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

UNITED STATES SENATE

ONE HUNDREDTH CONGRESS

FIRST SESSION

ON

GLOBAL CLIMATE CHANGE DUE TO MANMADE CHANGES IN THE EARTH'S ATMOSPHERE

JULY 16, 1987

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GLOBAL ENVIRONMENTAL CHANGE RESEARCH

THURSDAY, JULY 16, 1987

U.S. SENATE, COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION, SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE, AND NATIONAL OCEAN POLICY STUDY,

Washington, DC.

The subcommittee met, pursuant to notice, at 9:37 a.m., in room SR-253, Russell Senate Office Building, Hon. Albert Gore, Jr., presiding.

Staff members assigned to this hearing: John Graykowski and Penny Dalton, professional staff members; and Pete Perkins, minority professional staff member.

OPENING STATEMENT BY SENATOR GORE

Senator GORE. This hearing will come to order.

I would like to welcome all of our witnesses and guests today. This is a topic that is of great concern to this subcommittee and the National Ocean Policy Study. And this is a joint meeting of those two entities.

Let me begin by saying that my own involvement in investigating global climate change goes back six years and includes a number of congressional hearings which I have chaired and a number of others which I have been allowed to participate in through the courtesy of my colleague, Senator Chafee, Senator Max Baucus and George Mitchell and others.

During a hearing that I chaired in 1981, scientists first testified that manmade changes in the earth's atmosphere would cause a greenhouse warming. We also heard about ozone depletion which was first predicted in 1974. Today we will hear testimony that the scientific community has reached a new consensus that ozone depletion, the greenhouse effect and other global environmental phenomena are closely related one to the other, and that these manmade changes are endangering the global environment as we now know it.

Modern mankind has acquired the technology to catastrophically modify the fragile environment of our planet. The world environment, as we now know it, is threatened by the greenhouse effect, stratospheric ozone depletion, tropical deforestation and desertification. Our atmosphere is being heated up by the greenhouse effect caused by the buildup of carbon dioxide, chlorofluorocarbons and other anthropogenic trace gases which trap heat radiation.

If today's worse case scenarios become tomorrow's facts, we would then have only a few decades in which to ameliorate the

impact, an impact which could range from droughts in the Midwest to floods on the coasts. Some of the same gases implicated in the greenhouse problem, incidentally, are also culprits in causing ozone depletion.

The ozone layer protects all life on earth from harmful ultraviolet radiation. This ozone layer is under attack from chlorofluorocarbons and halons, chemicals which are manmade. The Environmental Protection Agency has recently projected that with present growth rates in the emissions of chlorofluorocarbons, there will be an additional 40 million skin cancer cases and an additional 800,000 deaths for Americans who are alive today and those born within the next 88 years.

For those unfamiliar with these environmental effects, they may sound more like a plot from a bad science fiction novel than a serious concern deserving public policy review of the highest order. But given the serious and potentially drastic impacts, Federal research and study efforts must place the greatest priorities on solving the mysteries surrounding global change. Otherwise future generations could experience a science fiction horror story that comes true.

Scientific effort to understand what man is doing to our planet is even more important when one considers that there are those in the current administration who seem to want to deny that we are harming our environment. There have been newspaper accounts of officials proposing floppy hats and sunscreens as personal protection from the effects of increased ultraviolet radiation. And though those reports were later denied, the controversy highlighted the efforts of some to weaken the United States' negotiating position in the current talks about the protection of the ozone layer.

The best way to protect the public is to protect the environment by limiting the production of ozone depleting chemicals. There is really no excuse for not doing that. This administration's approach of short-term solutions for very long-term problems is entirely unacceptable.

In cases where the risks of inaction are great, public policymakers must sometimes take action without complete information. We do not like to do that, but when the consequences of continuing irresponsible activity like the production of chlorofluorocarbons are so great, we must be prepared to act quickly.

We do depend on the scientific community for known information, for estimates of risks and for estimates of when more is likely to be understood more clearly. The United States Global Change Program can act as an invaluable resource for the kinds of information that Congress will need to make decisions about environmental policy. Long-term studies will give us a thorough understanding of what changes are occurring.

Interestingly enough the best and most complete collection of data on the atmospheric concentrations of carbon dioxide began back in 1957 as a result of the International Geophysical Year. At that time a sampling station was established in Mauna Loa, Hawaii, and today scientists are still collecting data from that station. These records show very graphically that we are altering our atmosphere in dangerous ways.

The greenhouse effect, ozone depletion, deforestation, and other global environmental issues seem out of scale when compared to the sorts of problems our political system is used to confronting. We must act now in order to put in place an effective, coordinated plan for understanding the changes occurring on our planet. The scientific agencies of the Federal Government are preparing now for this challenge. I urge the administration to listen to the conclusions of the scientific community and to cooperate with Congress in protecting our global environment. Though some of the important solutions appear presently to be of unprecedented difficulty, it is our responsibility to seek all possible solutions to these new threats to our global environment.

Let me insert in the record at this point statements from Senators Hollings, Riegle, and Pressler.

[The statements follow:]

OPENING STATEMENT BY THE CHAIRMAN

Today the Commerce Committee, the Science, Technology, and Space Subcommittee, and the National Ocean Policy Study will examine national and international research programs on global environmental change.

I continue to be concerned over increasing threats to our global environment. I also recognize the need for better information to deal with these problems. In May, Secretary of Interior Hodel reportedly considered a proposal calling for us to use hats and sunglasses to protect against harmful solar radiation. The Secretary's proposal provided excellent satirical material, but it also focused public attention on a potentially serious problem—atmospheric ozone depletion. Growing evidence implicates some manmade chemicals in the destruction of the ozone layer that shields the earth from ultraviolet radiation. Some of these chemicals also appear to be "greenhouse gases" and may contribute to climate shifts, changes in rainfall patterns and sea level rise. The more our scientists have learned about the problem, the more complicated the problem seems to become. Our understanding of global processes is far from complete and research is essential for determining policies which respond effectively to our concerns. I look forward to hearing how the scientific community plans to approach this global challenge. I also commend their foresight and cooperation in developing long-term research plans.

With respect to supporting the research proposed, the scientific planning process must be accompanied by a parallel evaluation of the funding needs. In light of our current national budget crisis, we must give careful consideration to allocating funds so that we avoid throwing money at research which provides interesting headlines in the daily newspapers but fails to provide information needed to make reasoned policy decisions. Because the proposed programs cut across agency guidelines and across scientific disciplines, coordination must be accompanied by a re-examination of our budget priorities. It may be necessary to move away from the agency-by-agency viewpoint which has characterized our budget process in recent years and create a program which is balanced to meet our research needs.

In addition to the research issues created, some of the predicted global trends raise disturbing management questions. For example, many of the members of this Committee have worked with me to develop a sound framework for coastal management. We have watched as coastal managers struggle to balance population pressures and the preservation or our fragile coastal resources. Now we are told that over the next 50 to 100 years, global sea level may rise at a much faster rate than it has in the past. Rising levels threaten to inundate developed areas and worsen current problems with beach erosion and shoreline retreat. Only by beginning now to develop management practices which consider the dynamic and shifting nature of our coastal environment can we expect to meet these unprecedented challenges.

OPENING STATEMENT BY SENATOR RIEGLE

The hearing that we will conduct this morning is very important to all of us. It is the first time that we have attempted to bring together all of the federal agencies that are involved in climate research, and to gain an understanding of the forces that are at work in the world which may affect the Earth's natural weather system.

There have been a number of recent studies to indicate that mankind's activities are having a measurable impact on the Earth's weather. It is far too early to tell how large that impact is, whether it is adverse or neutral, and how fast these changes might be occurring. Indeed, one reason for this hearing is to obtain a greater understanding of the amount of knowledge that we currently possess in this area, and more importantly what we don't fully understand and what must be studied in greater depth.

The evidence that we do have shows that atmospheric carbon dioxide is increasing at a tremendous rate. We know, for example, that carbon dioxide in the atmosphere can lead to an increase in global temperatures in the neighborhood of 3 to 5 degrees Farenheit. We know that an increase of this magnitude has taken more than 18,000 years since the last Ice Age, and yet it can be projected to occur in less than a generation. We know this, and yet we don't know what this might mean to the actual weather that we all experience. We can only suspect that the impact on the weather will be large and means that major changes may occur in the way all of us live.

Other evidence shows that the ozone layer in the atmosphere may be degrading due to the involvement of certain man-made chemicals such as freon and halon. The ozone layer is one of the few lines of defense against an uninterrupted stream of ultraviolet radiation hitting the earth's surface and causing terrible health problems to the population, and possibly changing the basic mechanisms of life itself in the cells.

We simply don't know the extent of the damage to the ozone that has occurred already, the rate that this damage might be occurring, and what the natural cycle of the ozone layer might be.

But we have to know these things, and we must begin the effort to find out the answers to all of these questions. The evidence is simply too great that something is happening to the basic structure of the Earth, the way it operates and the way that weather is moderated. It is clear that man has had an impact on the Earth system, and that this impact may be affecting the delicate balance that makes our planet unique in the solar system.

I look forward to the hearing today in order to gain a better understanding of the work that is currently being done and that will be done by all three of the federal agencies.

Opening Statement by Senator Pressler

Mr. Chairman, I commend the Committee for scheduling this hearing on the issue of Global Change. There is a growing recognition that certain environmental phenomena and processes must no longer be considered separately, but should be considered as part of an interactive, composite earth system. Moreover, it is believed by many that these phenomena land processes have had and will continue to have profound effects on all dimensions of our environment—the atmosphere, the oceans, the earth itself, and living organisms within our environment. Yet, by most accounts, we are unclear about how or why these phenomena and processes occur. Nor do we fully understand how human activities, such as the burning of fossil fuels or deforestation, will affect our future environment.

Today's hearing will assist the Committee in several ways as we examine these important issues. First, the hearing will provide the Committee with an understanding of what is at stake, or, put another, "What effect are these phenomena and processes having on our environment, and what are the likely consequences if we do *not* initiate a coordinated Federal program to better understand them and act accordingly."?

Second, this hearing will give the Committee an understanding of the research that the federal government is currently conducting and anticipating, along with the level of resources necessary to initiate a Global Change program and conduct it over a reasonable period of time. Regrettably, the pressures of our federal budget deficit are just as great now as ever before, and these budgetary pressures cannot be ignored in the consideration of resource commitments.

Third, this hearing should help the Committee understand what must be considered in establishing an interagency institutional framework for a Global Change program. If the agencies involved effectively coordinate their respective programs, a Global Change program could increase significantly our understanding of the environment and thereby lead to more effective action, where appropriate. Without this effective coordination, however, we run the risk of unnecessary duplication of effort and the loss of synergism between the agencies' respective programs.

Fourth, this hearing should give the Committee a better understanding of how a Global Change program might be coordinated with a similar international effort.

The global nature of these issues, as well as budgetary considerations, makes international cooperation a necessary and essential element of any national effort.

These are but a few of the issues that warrant this Committee's careful study. Certainly, we will also want to consider how to use effectively our existing national scientific and technological capabilities to meet the critical requirements of a Global Change program. For example, such a program will make extensive use of a satellite land-remote sensing capability. Yet, the future of our own Landsat system continues to exist in a state of uncertainty that can only carry over and affect adversely the planning for a Global Change program. If we expect to conduct a meaningful and productive Global Change program, we must maintain the critical capabilities to "do the job right". Otherwise, "why do the job at all"?

Furthermore, such a program will impose unusually large requirements for the development, analysis, and storage of data currently available, as well as for the data that would be newly acquired. Ready access to and proper management of this wide variety of global data will be critical elements of a Global Change program and will serve as a common link between academia, federal agencies, and the international scientific community. For these and other reasons, our existing national data processing and archival facilities should be considered as important elements in the research activities of such a program, as well as for the coordination and dissemination of its results.

With these thoughts in mind, Mr. Chairman, I join you in welcoming the witnesses who will appear today. The importance of their testimonies is underscored by the fact that the issues that are being addressed today may require significant public policy actions. I look forward to their testimonies and know that the Committee will benefit from their counsel and advice.

Senator GORE. I would like to call on our first witness, my distinguished colleague and friend, Senator John Chafee, who has been a real leader on these and other issues. And I want to thank you for the courtesy you have provided to me in hearings which you have held over on the Public Works and Environment Committee. I have enjoyed working with you and look forward to continuing that joint work.

STATEMENT OF HON. JOHN H. CHAFEE, U.S. SENATOR FROM RHODE ISLAND

Senator CHAFEE. Well, Mr. Chairman, first of all, I want to thank you and congratulate you for holding these hearings today. You have long been involved with this. You are no newcomer to this. You have devoted a lot of energy not only when you were in the House, but since you have been in the Senate.

And also, we all recognize that you have other current demands on your time. And for you to hold this hearing today, particularly after a hectic week that you have had, plus that we didn't get out of the Senate until something like 12:30 last night, shows your dedication and concern. And I want to congratulate you on that and say what a pleasure it has been to work with you on these issues in the past and look forward to continuing that relationship.

The problems, Mr. Chairman, of global change, specifically global climate change, often referred to as the greenhouse effect, and the depletion of the stratospheric ozone layer, have been the subject of numerous hearings, as you mentioned, before the Senate Committee on Environment and Public Works. What we have learned is that these combined environmental threats present all of us, policymakers and scientists alike, with a challenge that I believe and I think we can accurately say is larger and more important than any in recent history in the environmental world. So, there is a very real possibility that man, through ignorance or indifference or

both, is irreversibly altering the ability of our planet to perform basic life support functions.

Now, this may sound alarmist and extreme, but if we look at the evidence and if we look at the prediction of the scientists from around the world, we can only conclude that the risk is a real one. It is serious, and we just plain cannot continue—I should take out the word "continue." We cannot afford to ignore it. I do not want to suggest that we have ignored it.

The scientific community as a whole I believe should be congratulated for recognizing these problems and for bringing them to our attention. A significant number of scientists are telling us that these problems can no longer be treated solely as important scientific questions. They must now be seen as critical problems facing the nations of the world. These are problems that demand solutions.

Not all scientists, I regret to say, have been as farsighted and forthcoming. I am referring to the disappointing lack of leadership by the National Academy of Sciences. In recent years at a time when scientists from around the world are urging action and working to improve our understanding of global climate change, the Academy has addressed and commented on these problems with an unusually high degree of calm, caution and general disregard for the seriousness of the problems and the needs of the policymakers.

For example, at a National Academy of Sciences meeting on this subject last October, the chairman of that meeting refused to discuss any new evidence of ozone depletion and dismissed objections with a comment to the effect that this is not a no-growth panel.

Even though the meeting was convened at the request of the Senate Environment Committee, the needs of policymakers were treated as an annoyance rather than an integral part of the meeting. Such attitudes are particularly unhelpful. And I urge the committee to query the Academy on this particular matter.

Clearly we need to improve our understanding of global environmental problems. Interdisciplinary research projects, like the International Geosphere and Biosphere Program developed by the International Council of Scientific Unions, are extremely important. That new program has been characterized as the largest scientific program ever mounted.

Now, my reason for appearing here today is to say that such a program and parallel complimentary programs in the Federal Government are urgently needed. However, before we decide to commit billions of dollars to new research, we must ask ourselves and each Federal agency what are our research goals. What are our priorities? We need to be sure that the money will be used to solve real world problems.

The answers to the two critical questions are as follows. First, in my judgment the top priority should be global climate change, the greenhouse effect and stratospheric ozone depletion. That is the top priority.

Second, our goals should be the development of information that can be used to reduce the risk now, to reduce the environmental threat in the next few years, not several decades from now. We cannot wait 20 years for all the answers. By then it may be too late

to control or to reverse man-induced changes in our global environment, changes that threaten all forms of life.

There is a difference, Mr. Chairman, as you so well recognize, between the responsibilities we have as policymakers and the way the scientists can approach this. They can take the attitude that this needs study. We will look at it carefully. We will come back and report. But meanwhile, we may have set in motion events that cannot be reversed. And so, therefore, we as policymakers have to act without all the information in. And that is what falls upon us. Get the best information we can, and then proceed even though we don't have the last details right in place.

Mr. Chairman, I would like to submit for the record [1] an article from the July 9 edition of *Nature Magazine.* It is by Dr. Broecker of Columbia University, and it includes a number of intriguing, troubling, and no doubt controversial comments about the greenhouse effect and our government's poor track record in the area of environmental research generally. The article expresses dissatisfaction with the status quo and suggests that simply throwing more money at these problems will not solve anything.

I agree with those points and look forward to working with you to develop a program in which scientists and policymakers will work together to solve the problems of global climate change. I am confident that if we give the scientific community the support and the direction it needs, and if we all understand what our priorities and goals are at the outset, we can rise to the challenge of what may be—and I suspect you will agree with this—the greatest environmental threat now known to man.

I want to thank you.

Senator GORE. Well, I would agree with that, and I would go farther by saying that I think before the end of this decade, these twin problems will be recognized as the most serious environmental threats we have ever faced. They will be at the top of the environmental agenda for the rest of this century and on into the next century.

And I could not agree with you more when you say that policymakers must now be prepared to act notwithstanding the fact that all of the information is not yet completely available.

For example, the team of scientists which returned from Antarctica is still looking at the data they compiled during that visit. And it will be some time before a definitive peer review and analysis has been completed. But if you ask them informally what their feelings are about the connection between CFCs and the destruction of ozone, they will say, that, there is a 90, 95 percent chance that that is the cause of the ozone destruction.

And yet, we are in the midst of negotiations where the goal is ostensibly just to slow down the rate of increase, at least that is the practical consequence of the discussions now taking place. Our own EPA tells us that we would have to reduce the production of chlorofluorocarbons by 85 percent worldwide in order to simply stabilize the damage that is being done by these chemicals in the ozone.

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[1] See p. 149.

Would you agree with me that it makes sense for us to work for a complete phasing out of the production of these chemicals worldwide?

Senator CHAFEE. Oh, yes. I certainly agree with that. Our problem, as you know, is whether to take dramatic steps unilaterally—the U.S.—as opposed to trying to bring along the rest of these countries in a multinational effort of reductions of somewhat less than we could achieve ourselves. And I think the State Department is right in pursuing this international approach because if we go it alone, the attitude internationally was, well, if the U.S. is going to do it, and they are responsible for one-third of the CFCs in the world today, then we will lay back in the traces and won't do much. So, I think we are right. It is a high wire risk act we are doing, but I think we are right in trying to bring the others along. And as you know, there is a series of steps which would get to a 50 percent reduction over some 10 years—8 years.

But I think we have to try that. It may not work, but I have introduced legislation and am prepared to press that to go it alone if nothing comes out of Montreal or the agreements leading up to that. But I am hopeful that internationally they will be able to do something.

Senator GORE. Well, if I could continue the dialogue just briefly, I agree that we should make every effort to bring other producers of CFCs along with us. And these negotiations are very important.

And I think it is tragic that this administration has allowed internal disputes to shackle the efforts of our negotiators to provide the sort of leadership which we ought to be providing to the world on this issue. And we ought to be much more vigorous.

And I would just say again with respect to the 50 percent goal, if you look at that EPA estimates that tell us that we have to reduce CFC's by 85 percent just to do no more damage than we are doing now. In other words, these chemicals that are being put into the atmosphere are eating up the ozone layer. That damage is continuing so long as those chemicals are put into the atmosphere and they stay there for a long time. If we want to see next year and the year after an amount of destruction no more than what is going on today, we have to reduce the production by 85 percent. If we reduce it by 50 percent, there will still be a steady increase in the amount of damage being done each year.

So, it is like we have blinders on. And if the consensus in scientific community is in fact correct, we are crazy to be talking about only a 50 percent reduction. This is madness. We ought to be looking at a much more drastic reduction.

Now, what about a unilateral approach? I agree with you that it must be a multilateral, international approach. But if Japan and the Soviet Union and the European producers continue to drag their feet and fail to recognize the global damage that is being done, we must be prepared to consider much stronger action.

There are many products which involve the use of these chlorofluorocarbons. If these negotiations are not successful and if the other major producers fail to go along, I believe we ought to give serious consideration not only to moving toward a ban in the United States, but to exploring the possibility of preventing the purchase in this Nation and the import into the United States of

any product that includes these dangerous chemicals. And that includes semiconductors, which are cleaned with chlorofluorocarbons. It includes a variety of other industrial products. And there would be a benefit to this Nation from such a course of action.

In addition to providing leadership, if the world eventually came to the conclusion which many of us have reached, then the nation which first began producing alternatives to chlorofluorocarbons would have an advantage in the world economy of tomorrow because we would be well-positioned to dominate commerce in the production of a whole range of chemicals and products that would become much more valuable in the world economy after we moved away from these chlorofluorocarbons.

One other point which I wanted to underscore in——

Senator CHAFEE. If I just might.

Senator GORE. Yes, please respond.

Senator CHAFEE. I just want to interject if I might.

The legislation I have introduced is exactly what you describe.

Senator GORE. And I am a co-sponsor.

Senator CHAFEE. And you are a co-sponsor.

Senator GORE. We are about to convince each other.

Senator CHAFEE. And I think we can both agree it is outstanding legislation.

Senator GORE. Well-written.

Senator CHAFEE. But the key point, as you say, is the trade effects that it says not only that we give them up, but we won't import those products that are made with it from other countries. And so, you have really got a cheerleader here backing up everything that you have been saying.

Having said all that, I do want to point out that our negotiators at the last round in Brussels were still pressed. We are pressing for—I believe it was a 95 percent reduction.

And I want to commend Ambassador Benedict who I think has been outstanding in these negotiations. He is really pressed. And the State Department has done a good job. And the administration position, not going as far as we would like for the 95 percent, but they finally came down to a good position, not perfect, but certainly encouraging.

Senator GORE. Well, I must respectfully disagree slightly with that. I agree totally with your assessment of Ambassador Benedict's work. I think he has done an outstanding job. But personally I think that it is outrageous that he and his colleagues in charge of the negotiations have had to spend so much time and energy fighting others in the administration who are constantly trying to weaken our negotiating position.

Here, for one of the only times in this administration, we have had an opportunity to provide world leadership on an important environmental issue. We had a good set of negotiators who were going to this forum and making the case in a way that ought to make Americans proud, and then they are stabbed in the back by others in the administration who say, oh, well, the industries involved may lose a little bit of money if we continue to pursue this kind of position. And then they are forced to water down the proposal and instead pursue an objective. This, as I noted earlier, will steadily increase the damage being done to the ozone layer.

In any event, one other——

Senator CHAFEE. Let me just say one thing.

Senator GORE. Please respond.

Senator CHAFEE. I know there are other witnesses, and I will make this quick.

In the best of all worlds I would go for a 100 percent reduction, go all the way. I just understand the negotiating problems that they have. And you know, we are dealing with countries that have not even cut out freon from aerosol cans——

Senator GORE. Right.

Senator CHAFEE [continuing]. The easiest step of all, something that we did some 10 of 15 years ago. So, we get to the problem that you described and I mentioned also of whether we are trying to bring along the others and have an international or whether it is just us going alone and not considering the effects of the others. Whereas I wish we could have a much stronger position, I think we have got a position that hopefully they will latch onto.

Senator GORE. But that is not what caused the modification of our position. Our negotiators came back and said, look, we believe we can make more progress if we water down our approach a little bit. But instead, they had to water down the approach in order to strike a compromise with the commercial interests represented within the administration who were saying, look, don't go this far. And that is what I think is so tragic about it.

Let me say while you are conferring there that I took note of your statements about the NAS. And our next witness will have a chance to respond there. I would just say on my own account that I have known them to do a number of studies on this subject, and they have come to the conclusion that the atmosphere will, indeed, warm. And they have cited uncertainties. And they have been traditionally reluctant to make strong policy statements on how Congress should act. But they have worked very closely with the U.S. Global Change Program. And as I say, Dr. Press will have a chance to speak for himself.

But did you want to respond to my earlier statement?

Senator CHAFEE. No. I just wanted to say that I don't want anybody to leave here with the impression that I am not for the strongest, toughest reductions that we can possibly get.

You are right in your assessment that back-room bickering in the administration was not helpful at all to our position. And there was a constant effort to undermine Ambassador Benedict and what he was trying to do. But I think a good deal of that was able to be rejected——

Senator GORE. Not all.

Senator CHAFEE [continuing]. Although undoubtedly they could have gone with a tougher position than they did.

However, let's hope that we can get this anyway, and then perhaps come back and do even more.

And again, I want to thank you for these hearings.

Senator GORE. I am proud to have a chance to work with you. Thanks for leading off this morning.

Senator CHAFEE. Thank you.

Senator GORE. Our next witness is a good friend, Dr. Frank Press, President of the National Academy of Sciences and Chair-

man of the National Research Council. Dr. Press, please come forward and join us at the witness table. And please introduce to us your colleague who is joining you.

STATEMENT OF DR. FRANK PRESS, PRESIDENT, NATIONAL ACADEMY OF SCIENCES, ACCOMPANIED BY JOHN PERRY, EXECUTIVE DIRECTOR, BOARD ON ATMOSPHERIC SCIENCES AND CLIMATE

Dr. PRESS. Thank you, Senator Gore.

I brought with me John Perry, who is an atmospheric scientist and the executive director of our Board on Atmospheric Sciences and Climate.

Senator GORE. Welcome.

Dr. PRESS. May I start——

Senator GORE. Please.

Dr. PRESS [continuing]. With a response to Senator Chafee?

Senator Chafee is very highly honored in the oceanographic and atmospheric community. Over the years, he has exercised a leadership position, as you have stated, in building our programs and our studies of the oceans and the atmospheres and building strong institutions in his own state. That is why I was disappointed in that he was poorly informed about the work of the Academy in these very important areas.

I would like to mention a few of these. The first studies pointing out the problems with the ozone layer and its destruction were Academy studies. The regulations banning the use of freon in aerosol cans is the result of an Academy report.

The International Geophysical Year and the IGBP, this new international program, are programs that were brought to the attention of international community by the National Academy of Sciences.

Our work on acid rain is widely recognized, I think in changing the views of the administration that not only is more research needed, but we better get started modestly, perhaps too modestly, with some mitigation programs.

The foundations for the regulatory legislation in the 1970s that led to the Environmental Protection Agency and all of its statutes were laid by reports of the National Academy of Sciences.

I do not think a committee of Congress would want us to say more than we know on any of these issues. We would like to tell you in all of our analyses what we know and what we do not know, and then to rely on the judgments of Congress and the executive branch—about what actions should be taken.

I was very impressed with your own opening statement. And for that reason, I would like to start with the last sentence in my own statement and put it up first, and that is that the most important policy issue facing Congress and the executive branch is precisely what you had said on matters such as carbon dioxide, ozone, acid rain and the others. When do we know enough to start paying the costs of mitigating actions against potential disasters of uncertain but possibly enormous dimensions? That is the key judgmental issue that I think the American people expect of their elected offi-

cials. And I am glad that you are concentrating precisely on that issue.

Well, let me start with my written testimony.

I am pleased to have the opportunity to discuss with you the beginnings of a major scientific initiative seeking to understand the ways in which the world we inhabit is changing.

Through the processes of nature and the activities of people, the earth is changing. This, of course, has always been the case, but until recently the change has been slow so that natural systems have had long periods in which to adapt. But the pervasive impacts of human actions have increased the rate of change and altered the extent and scope of the effects. For example, man is a more important agent today in modifying earth's land surface than geological processes. And that is an extraordinary statement. Billions of years of geological processes, and in a few decades now man is a more important agent than nature.

The clear and growing evidence of large-scale anthropogenic change poses serious questions for all the nations of the world. As we alter the atmosphere and the oceans and the land, we set in motion forces that may profoundly affect conditions on our planet. What are the implications of these changes for climate, for water supply, for food production, for human health, for natural ecosystems? And if we are making potentially detrimental changes on our planet, what can we do about it? How can we balance the risks and benefits of various courses of action? At what point does it become appropriate to take actions, perhaps global actions, to reduce the potentially damaging impacts of our technologies on the earth?

The so-called greenhouse effect illustrates the complex mix of scientific, normative and political questions inherent in issues of global change and the importance of first developing a basis for sound scientific judgments through cooperative research efforts across disciplinary and international boundaries.

So far, much of the research attention and public concern have focused on accumulations of carbon dioxide as a cause of rising atmospheric temperatures. Sources of CO_2 are reasonably well-known, but what remains uncertain and controversial are questions like: when will CO_2 concentration reach a danger point; what actions would reduce the problem; and how can international cooperation be secured in effecting a solution when it becomes imperative.

It is understood within the scientific community, but not widely recognized elsewhere, that accumulations of methane and other trace gases may generate as much of a greenhouse effect as CO_2. For example, for the past 10 to 15 years, methane concentrations in the atmosphere have been increasing at a rate of one to one and a half percent per year, considerably faster than the rate of CO_2. Sources of methane include livestock, swamps, rice paddies, termite metabolism, biomass burning. But the reasons for the methane increases are not well understood. It is not even known whether emissions are increasing or alternatively, whether there has been a change in the atmosphere's ability to transform methane into innocuous gases.

Answers to these questions are likely to require the combined expertise of specialists in so many different fields in different parts of the world. The answers are needed before we can sensibly devise strategies to halt the increase in methane concentration.

And the questions that must be addressed are difficult ones, questions for which there are no definitive answers. But one thing is clear. Any good answer will require that we develop an understanding of global functioning that allows us to appreciate the processes that affect the atmosphere, the oceans, the solid earth, the space environment of earth and their interactions. What is clearly called for is a major international and interdisciplinary effort to increase our knowledge of the earth. Such a program must bring together people and institutions that do not normally interact and scientists from many countries that poorly interact.

Multi-national, multi-disciplinary cooperation has a long history in the earth sciences and has played a crucial role in the development of our understanding of the planet's workings. In the seventeenth century, Hadley laboriously developed an understanding of the global atmospheric circulation and the trade winds from a worldwide collection of ships' logs. By the nineteenth century, formally organized international scientific activities began to take shape. International weather observing networks emerged, and a First Polar Year was organized in 1882–1883. In our own century, a Second Polar Year was held in 1932–1933.

In the post-war period, proposals for a Third Polar Year evolved into the International Geophysical Year of 1957–58, which has been termed "perhaps the most ambitious and at the same time the most successful cooperative enterprise ever undertaken by man." Tens of thousands of scientists from sixty-seven nations participated in the IGY at a cost of perhaps as much as $2 billion. A wealth of new scientific findings flowed in virtually all branches of the earth sciences. Moreover, the program pioneered the use of satellites for Earth observation, enhanced support for basic science throughout the world, and greatly strengthened the cooperative bonds between nations in the pursuit of common scientific goals.

The IGY set the stage for a number of successor efforts focused on one or another scientific problem area. For example, the Global Atmospheric Research Program (GARP) addressed the large-scale circulation of the atmosphere and the problem of weather prediction. The observing and research projects organized under the aegis GARP, notably the Global Weather Experiment of 1979, led directly to major improvements in extended-range weather prediction. Today, the International Council of Scientific Unions, the World Meteorological Organization, and a number of other international bodies are cooperating in a similar manner in the World Climate Program.

Since the IGY, scientists and engineers have developed powerful and effective tools that enable us to gather information about how the earth works. And you will hear more about this from our later speakers.

In the past few years emerging concerns about a broad range of global change issues, coupled with our new observational and analytical capabilities, prompted a number of initiatives. A group of scientists under NASA's auspices called for a program of global

habitability. Within our own organization of the National Research Council, Herbert Friedman, one of our leading members, proposed the basic concept of the IGBP. And we had a workshop in 1983 which led to the concept which subsequently was adopted by the International Council of Scientific Unions.

We are very pleased that ICSU, the International Council of Scientific Unions, approved the establishment of this new program and formed a special committee for its implementation. The first meeting of that committee is in progress at this very moment.

Although the scope is still emerging, the ICSU planners have already stated the focus of the program: to describe and understand the interactive physical, chemical and biological processes that regulate the total earth system, the unique environment that it provides for life, the changes that are occurring in the system and the manner in which they are influenced by human actions. And that is the focus given by an organization that essentially represents all of the scientists from all of the nations of the world, the Eastern Bloc, the Western Bloc, the large countries, the poor countries.

Clearly, an effort of this scope and magnitude is a rather awesome challenge to science and to the institutions of science. And we certainly accept that challenge and will undertake this program. We will need virtually unprecedented international cooperation in exchanging data. We will need to marshall the contributions of scientists from all countries, from many disciplines within our own country, and we need a long-term commitment on the part of our government to these programs.

As we will hear shortly, the Federal agencies have supported and participated fully and with growing enthusiasm for these programs. The National Science Foundation, for example, has reorganized and expanded its earth science activities under the label of global geosciences. NASA has made these problems the central focus of its earth science and applications program. NOAA is organizing an integrated effort in climate and global change, and other agencies are developing related programs. And the later witnesses will describe the responses of the scientific community and the government agencies to this challenge.

I am proud of the involvement to date of my own organization, the National Research Council, in the conception and development of an international global program. We intend to continue our commitment to the idea and to the program. I am heartened by the active and enthusiastic support of a number of government agencies within this country and by the worldwide recognition of the importance of international cooperation. And I am pleased by the interest of Congress, for in the end the success of this program will depend as much on the understanding and support of the legislative and executive branches as on the cooperation of scientists and governments throughout the world.

In closing, it may be helpful to mention some of the policy issues that almost certainly will arise and to which this committee can facilitate solutions through its oversight and legislative activities.

A research effort of the complexity and magnitude I have outlined requires stable funding over a relatively long period. Staying the course has not always been a hallmark of Federal research support.

This is a program that cuts across the responsibilities of many agencies. The adequacy of agency commitment and participation should be a matter of concern to Congress.

It is rarely a simple matter to determine when solutions to scientific problems require a genuinely interdisciplinary approach. And it is even more difficult to ensure that productive collaboration across traditional disciplines occurs. For some problems the use of novel funding mechanisms, such as group or center grants, may be advisable.

National security concerns about the exchange of research data on global change may in some cases be legitimate, although I cannot give you too many examples of that. But in most cases they may pose an unnecessary obstacle to international collaboration. And that is a matter of concern.

And then let me end where I began. I think this is the most important policy issue facing Congress and the executive branch when we start taking action on problems of this order of magnitude that can be enormous where there is some scientific uncertainty. That requires judgment of the highest order, and that is what we expect I think of our elected officials.

Thank you.

Senator GORE. Well, thank you very much. I enjoyed your statement.

Let me ask a number of questions. First of all, you used the word anthropogenic which means, does it not, effects caused by mankind itself? And you said that the changes in global environment caused by the activities of mankind are now larger in scale than the changes caused by natural forces. Correct?

Dr. PRESS. In some cases that is certainly the case. Especially in the modification of earth's land surface, that is definitely the case.

Senator GORE. And of the upper atmosphere.

Dr. PRESS. That is the potential we are all worried about, yes.

Senator GORE. So, one of the reasons why we have difficulty dealing with this issue as a nation, as a civilization, is that it is beyond our historical experience in this sense. Only recently has human civilization become large enough and powerful enough to cause global changes on this scale. Since we have never had to take into account those kinds of effects in the past, we are not used to doing it. And we have trouble realizing that the cumulative impact of industrial civilization has become as large and potentially damaging to the global environment as it now has become.

So, when you approach the question of when we act and how much information we need in order to justify action, that question has to be approached with that new realization in mind, that we are having an impact every single day much larger than our civilization has ever had in the past.

Do you agree that—and I will ask your associate to also comment on this—it is likely that chlorofluorocarbons represent the principle reason for ozone depletion?

Dr. PRESS. I would say that that is the consensus of the scientific community. There may be some exceptions to that point of view, but by and large, most of the experts in the field would accept that statement. There may be other factors involved as well, the effects

of fertilizers, large-scale use of fertilizers, and emanations into the atmosphere from that. But the CFCs are certainly a major factor.

Senator GORE. And halons.

Well, now let me use that as a model then. Where the greenhouse effect is concerned, many scientists have now projected that the current rate of increase in CFC production will mean that within a few years 30 percent of the greenhouse effect may be caused by CFCs even though the total volume of CFCs is minuscule compared to carbon dioxide, for example. Each molecule is said to be 10,000 times as damaging in greenhouse terms as a molecule of carbon dioxide. And therefore, as production increases, they become responsible for a larger portion of the greenhouse effect. Would your colleague agree with that assessment?

Mr. PERRY. That is right. The chlorofluorocarbons are absorbing radiation in wavelength bands that are otherwise fairly clear. So each new molecule is a new piece of absorption.

Senator GORE. All right. Now, let me use that as an example. We have uncertainty in science about the exact role played by chlorofluorocarbons in contributing to the greenhouse effect. We have uncertainty about how the cloud system may mitigate the greenhouse effect. We have uncertainty about the release of carbon dioxide in the oceans as they warm, and other uncertainties. And the cumulative impact of those uncertainties on many scientists has the effect of saying, well, let's just wait until we know a lot more.

If there is a good chance that chlorofluorocarbons are contributing greatly to the greenhouse effect, and if there is an excellent chance, indeed, if there is a consensus in the scientific community that they are the main reason for the destruction of ozone, then public policymakers ought to view the uncertainty about their role in the greenhouse effect against the background of the other damage they are doing and come to an overall judgment that is absolutely crazy for us to continue producing these chemicals.

In other words, if they ought to be banned for other reasons anyway, then that should lead us to a different conclusion about the viability of public policy steps now to mitigate their role in producing the greenhouse effect.

Let me take another example. We know that the destruction of forests around the world is also contributing to the greenhouse effect. You would agree with that, would you not? Some 15 to 20 percent of the greenhouse effect some scientists have said can be attributable to deforestation because the earth's capacity to absorb carbon dioxide is diminished by deforestation. It sets in motion more methane combined with some of these other forces, and it increases the greenhouse effect. Would you agree with that?

Mr. PERRY. That is perhaps the most complicated single area of the greenhouse effect, but the net effect of changes in the land surface has undoubtedly contributed to it.

Senator GORE. Okay. So, there is uncertainty in the scientific community about the exact role played by the destruction of rain forests and deforestation generally in the greenhouse effect. But we know that there are other reasons why the world as a whole ought to be concerned about the destruction of rain forests. We are losing species. The soil will not regenerate its fertility because it is very fragile. It has other harmful effects, contributes to soil erosion, et

cetera, et cetera. There are other reasons why that problem ought to be attacked anyway.

And so, when we look at the uncertainty about the role of deforestation, and the destruction of rain forests in particular, where the greenhouse effect is concerned, we ought to see that uncertainty against the backdrop of our knowledge that that ought to be stopped anyway. And so, the likelihood that it is playing a role in the greenhouse effect ought to spur us on to confront that aspect of the problem. You could say the same thing about energy conservation. There are other reasons why we ought to move in that direction.

And so, in addressing what you identified, Dr. Press, as the central issue, when do we know enough to justify action, my response is that public policymakers ought to look at the big picture and realize that the time for action is now. It is crazy to continue producing chlorofluorocarbons. They are damaging the world's environment. There are substitutes available. We should move now toward a ban on chlorofluorocarbon production—not all chlorofluorocarbons, but those that are implicated in the destruction of ozone and in producing the greenhouse effect.

Similarly, the time is now to try and organize a worldwide effort to halt the destruction of rain forests in the world. It is crazy to allow the continued destruction of rain forests at the current rate. Somebody calculated that if we continue at the current rate—and of course, you never do, but if we continue at the current rate, they will be completely gone shortly after the turn of the century. Well, that is wrong. And the fact that that destruction plays a role in producing the greenhouse effect is yet another reason for action there.

Now, what you have proposed is a very interesting program. In one sense I want to compliment you on it. You and I have talked for a number of years now. As you know, I have for several years proposed an International Year of Research on the global atmosphere modeled after the International Geophysical Year. If I am not mistaken, you personally participated in the International Geophysical Year in 1957. Isn't that correct?

Dr. PRESS. That is right.

Senator GORE. Well, I agree with your assessment of how successful it was just looking at the results. And using that as a model, I proposed a few years ago an International Year of Research on the global atmosphere in order to improve the information available, in order to build a greater consensus in the world on the need for action on ozone depletion and the greenhouse effect and the destruction of the rain forests. And I still believe that that is needed. I have been unable to interest the administration in it, but maybe there will be a better opportunity to do that.

In any event, what you have proposed is ambitious. And I think it is a good idea. But let me tell you what my problem with it is.

You have outlined a 10 to 15 year program that would put us well into the next century. Then one would anticipate a number of years for a worldwide debate on the findings, on what the proper response should be. And pretty soon we are into the second decade of the next century. And yet, the atmospheric scientists tell us that the damage is occurring now, that many of the effects have already

been locked in place, and that if we dally around with this problem for another decade, then some of the much worse effects could already be locked into place.

It seems to me that a sense of greater urgency is needed. And while I applaud the specific proposal—and I have looked at your literature. I think it is terrific. I really do. And you have so much more experience than I do in international scientific cooperation that I know your proposal is informed by what you believe to be a sense of realism about what can be accomplished.

But again, this problem is out of scale when set against our historical experience. And the response must be different from the response we have organized of problems in the past.

Do you think that your program would move along too slowly and produce results after the time for action has already been here? See, I think the time for action is now.

Dr. PRESS. In proposing a program that may take 10 or 15 years, we do not imply that governmental leaders should suspend actions until the conclusion of that program. There is a lot of uncertainty in what we know now, but we also know a great deal. And what we know now could be the basis for action at this time along the lines of mitigation that we have already discussed. And these actions may differ for each of the different problems that we face.

I have to be careful about going beyond my own organization's studies and recommendations. But I am sure that you do expect me to give you some of my own views on some of these issues, and with care I will do that.

I believe that when it comes to climatic change as a result of carbon dioxide, the consequences are uncertain but they could be so devastating that I think we should start planning at this time for alternate energy sources, conservation, a new kind of nuclear energy source that is intrinsically safe perhaps, certainly a greater emphasis on solar energy and other methods of deriving energy because we are indeed facing the prospect of not being able to use fossil fuels in the next century.

It takes from 25 to 50 years, perhaps even longer, to change our energy economy, so to speak, how we derive our energy. And by the time we are able to do that, we may well be into a serious world problem. And so, I do not believe it is premature right now to start planning and perhaps investing research funds into the new energy strategies that we will probably be faced with in the next century.

With respect to ozone, I was very pleased with the administration's world position, leadership position, on the beginnings of a CFC reduction program, production reduction program. We did take the leadership. We fought very hard for that position, as you know.

I was also disappointed about the back-fighting here in this town. But I think that the administration in its judgment recognized what you have just recognized; namely, that the consequences of ozone depletion are so profound and the costs of decreasing the production of CFCs are not that great compared to the consequences, that we had better get started. They may not be moving as rapidly as you would like to see them move, but at least it is a start. And so, I supported that position as well.

So to conclude succinctly, we need to learn more about these scientific questions, but that is not a reason not to start right now with governmental policies to begin a mitigation program for the consequences that we face.

Senator GORE. Very good. Well, I certainly appreciate your testimony here today and your leadership at the NAS and the contribution made by the NAS and the National Research Council on these problems. And thank you both very much for appearing.

[The following information was subsequently received for the record:]

NATIONAL ACADEMY OF SCIENCES,
Washington, DC, September 24, 1987.

Hon. ERNEST F. HOLLINGS,
Chairman, Committee on Commerce, Science, and Transportation,
U.S. Senate, Washington, DC.

DEAR SENATOR HOLLINGS: Thank you for the opportunity to respond to your further questions relating to the July 16, 1987, hearings on the Global Climate Change program. It was a pleasure to discuss with your Committee the vital issues associated with this topic, including some scientific initiatives.

Let me now turn to your specific questions:

Question 1. In responding to potential threats posed by global environmental change, the sensible course of action lies in preventing the problems which we can anticipate now, rather than in attempting to deal with them once they become critical. Implementing preventive policies is a time-consuming process, particularly if it involves international negotiations. The International Geosphere-Biosphere Program (IGBP) has been proposed as a long-term research plan which would begin in the 1990's and continue into the next century.

Can the IGBP provide the timely scientific information needed to develop sound policy and avert an environmental crisis?

Do you have any suggestions for improving the integration of new scientific information into that policy making process?

Answer 1. The International Geosphere-Biosphere Program.

As you observe, the IGBP is expected to be a long-term effort. Its aim is to gain an understanding of changes in the global environmental system over periods of decades and beyond. Developing this understanding will clearly require a correspondingly long-term commitment to observation and research.

The need for long-term research efforts does not imply that we must wait decades for useful results. We should expect a slow, but accelerating growth in understanding of how the earth works and how best to manage it. The output of the IGBP will not be a single result of recipe, but rather a stream of increasingly deeper insights on how our complex planet operates.

The integration of scientific understanding and policymaking is, and will remain, a difficult art. Scientific information is always imperfect and incomplete. Scientists are doing their best to put bounds on the great uncertainties in our understanding of this planet, but nature guards her secrets well.

We must somehow develop and implement prudent policies in a context of inescapable uncertainty. Prudent policies can best be developed by policy-makers and scientists working together, each bringing to the task their best understanding of natural and political worlds. The extensive hearings held by the Congress this summer are certainly highly useful steps in that direction. A range of other, less formal activities would also be helpful. For example, Congressional workshops on integrated earth system studies have been organized in the past two years by the University Corporation for Atmospheric Research. These brought together a selected group of leading scientists and key Congressional staff members for several days of frank and open dialog. Similarly, the National Research Council is planning a seminar for the Congress on current issues in atmospheric change. Such activities take a great deal of time and effort, but I am convinced that there are no shortcuts to achieving a mutual understanding of the scientific issues that demand policy attention and the options and constraints that policy-makers must consider.

Question 2. Your experiences with the International Geophysical Year (IGY) in 1957, and as president of the National Academy of Sciences provide you with unique perspective on international scientific endeavors.

What recommendations would you make as a result of participating in the IGY and other international science programs in terms of: setting up the IGBP itself,

conducting business advisory apparatus, national and international orgnaizations, Federal coordination?

What types of international involvement are most important—e.g. financial support, facilities, participation in the global observation network?

Answer 2. International Scientific Endeavors.

International scientific programs such as the International Geophysical Year (IGY) and the Global Atmospheric Research Program owed much of their success to two factors: maintenance of scientific integrity and strong governmental support.

The basic organizational structure of the IGBP seems quite sound. The planners of the IGBP have drawn liberally upon this experience in setting up its machinery. An independnet ICSU Special Committee is to provide the scientific direction, backed up by national scientific committees such as the NRC's Committee on Global Change. I think that this network of independent and expert bodies will provide sound scientific guidance for the program. Within the U.S. federal government, agency programs are showing excellent support for the program, and interagency coordination seems to be taking shape in an encouraging fashion. At the initiative of the OSTP, a Committee on Earth Sciences was established. This Committee has not yet become effective, but the principal agencies seem determined to make it a useful vehicle. I believe that we can develop a well-focused and productive program, implement it effectively, and keep it on track.

I see two weaknesses in the structure of the IGBP at present, however. First, there is no high-level formal endorsement of the program by either the President or the Congress. In GARP, for example, every President from John F. Kennedy through Jimmy Carter specifically endorsed the program. A Presidential declaration or a Congressional Joint Resolution backing the program would be reassuring and helpful. US-USSR cooperation in the IGBP might also be considered in the context of near-term summit meetings. Secondly, there is as yet no international intergovernmental mechanism for implementing the program. This gap is not yet troublesome, since the scientific program is still undefined. However, as concrete multi-national projects are developed, some sort of intergovernmental mechanism for their coordination and implementation will have to be put in place. Our Committee on Global Change is giving some thought to these issues and may have some recommendations in the near future.

The U.S. contribution to the IGBP will, of course, be crucial. Our space-based observing systems will be the core of the observing system. Our scientific community will make major contributions to the program's intellectual development and will perform a major fraction of the needed research. I hope also that we will reliably pull our weight in supporting the international infrastructure—both intergovernmental and nongovernmental—that underpins programs of this magnitude.

Question 3. Your testimony indicates that the cost of the IGY was around $2 billion.

How do you expect the costs and level of effort anticipated for the IGBP would compare?

Do you have any sense of how the current international willingness to invest in the IGBP would compare with international support for the IGY in 1957?

Answer 3. Funding.

The cost of the IGBP is almost impossible to estimate at this early stage. A preliminary review by the federal agencies at last summer's initial meeting of our Committee on Global Change revealed a current level of relevant efforts measurable in the tens of millions—much more if one includes all relevant satellite programs. I expect the total expenditure to exceed substantially that of the IGY.

Although the IGY was carried out in very different times, I believe that the degree of international enthusiasm and willingness to invest is quite comparable. There is widespread support in Europe, and Soviet Union, China, Canada, and many other countries. The program is off to a much better start than most of its predecessors.

Question 4. In the past two Congresses, legislation has been introduced to establish "international years" patterned after the IGY. Proposals include an International Year of the Greenhouse Effect and an International Space Year.

Do you feel that either proposal would meet with the success of the IGY?

How would such initiatives fit into the research planned in the IGBP?

Answer 4. International "Years."

A 1985 legislative proposal led the Academy and the International Council of Scientific Unions (ICSU) to develop concepts for an International Space Year (ISY) to begin in 1992—the 500th anniversary of Columbus' voyage to the new world, and the 35th anniversary of the International Geophysical Year. The ICSU established an ad hoc planning group, and in response to a request from this group our Space

Science Board developed the concepts outlined in the attached paper. The document proposes activities in two areas—science and applications and education and public understanding. For the most part, these activities would be based on already planned programs. The special role of the ISY would be to coordinate and focus these efforts and to publicize and disseminate their results. It would "acknowledge and celebrate the benefits of space for all humanity."

In contrast, the IGBP is a highly-focused international collaborative effort in basic research that has been many years in gestation and is expected to continue for many decades to come. The two efforts should be viewed as complementary, not competitive. Indeed, the implementation of the ISY at approximately the same time as the first field activities of the IGBP should prove highly beneficial.

As you know, the International Year of the Greenhouse Effect was proposed in Concurrent Resolutions in the Congress early this year. The resolutions envisage that the "Year" would initiate a major and extended cooperative international research program on the impact of changing concentrations of radiatively active trace gases on climate and human welfare. The resolutions correctly highlight a crucial environmental issue. The atmosphere is the one unique component of our planet that makes life possible. We cannot take lightly the clear evidence that we are changing it in fundamental and potentially harmful ways.

For well over a century, scientists have been concerned about the implications of atmospheric changes for global climate and human welfare. The Academy has conducted several studies in recent years, including the 1975 *Energy and Climate* report, the 1983 *Changing Climate* report, and the recently issued report of a workshop, entitled *Current Issues in Atmospheric Change.* Internationally, ICSU and the World Meteorological Organization (WMO) have been conducting the World Climate Research Program, whose principal focus is the greenhouse gas problem. A number of international assessments have been carried out, and possibilities for a standing international mechanism are currently being discussed in WMO and UNEP circles. Finally, the IGBP is addressing the greenhouse gas problem in the context of the wide range of long-term, global-scale environmental changes. I believe that the proposals for a new program specifically addressing the greenhouse gas issue should be viewed in the framework of these numrous efforts.

An International Year of the Greenhouse Effect might at some point be an effective way to raise consciousness worldwide about the nature and seriousness of the problem. Furthermore, the goals of the draft resolution should and must be pursued. For the time being, however, I believe that the greenhouse gas problem should be addressed in the context of the related problems of human activity and environmental change. As recognized in the planning of the IGBP, all components of the earth system are interlinked on all but the shortest of time scales. Moreover, many of the same substances are involved in acid deposition, ozone depletion, and climate change. As expressed eloquently in the recent report of the World Commission on Environment and Development, the environmental changes that trouble us derive from a few basic social developments—population growth and urbanization, industrialization and energy production, and food production. I think that we would be better advised to support integrated programs of fundamental research such as the IGBP than to focus on a specific problem, even such a central issue as the increase in greenhouse gases.

Question 5. Please evaluate the U.S. Global Change Program planned as our national contribution to the IGBP.

Will the initiatives proposed by the National Science Foundation, National Oceanic and Atmospheric Administration, and the National Aeronautics and Space Administration provide a comprehensive U.S. program?

Should more effort or financial support be placed on some areas or does program development appear to be balanced in its approach?

Do you feel that adequate participation is planned for other federal agencies e.g. the Department of Defense, the Environmental Protection Agency, Department of Interior?

What do you see as the most effective role for the National Research Council in development of the U.S. program?

Answer 5. The U.S. Global Change Program.

In respone to the IGBP, many Federal agencies have initiated imaginative programs. These plans were reviewed in broad terms at the first meeting of our Committee on Global Change, which will serve as the U.S. National Committee for the IGBP. They compose an exceedingly broad program that would largely span the compass of the IGBP.

These programs—indeed the IGBP itself—are not yet fully developed—so it is premature to say whether they will constitute comprehensive U.S. response to the chal-

lenge of the IGBP. It is nevertheless clear that all of the agencies within the limits of their missions and capabilities are approaching the program seriously.

There are, however, grounds for concern about the infrastructure for the program—instrumentation, platforms, data management, and people. We will need a large commitment of resources over a very long period, in which there will be many competing demands on our national resources.

I believe that the most effective role for the National Research Council will be that chosen by our Committee on Global Change: to act as a focus for communication and coordination among the U.S. scientific community, federal agencies, international scientific bodies, and the scientific communities of other nations. I envisage that we will assess proposals developed internationally in terms of U.S. interests and capabilities, review U.S. programs in terms of their contributions to an integrated effort, and from time to time put forward new proposals for the consideration of the agencies and the international community. We shall also promote the flow of ideas and results through symposia, workshops, and other means. We do not intend to assume a management role, as the Academy did in the IGY.

Question 6. It is my understanding that the federal government supplied one third of the funding for the IGY; the rest of the U.S. contribution came from universities and other private institutions.

Does the approach of a federal-university partnership have advantages (other than the savings to the U.S. Treasury) over a federally controlled program? What are those advantages, and do you see an active effort to involve private institutions in the IGBP effort?

Do you believe that private institutions and universities have the same ability today to cooperate with IGBP efforts that they had in 1957?

Answer 6. Federal-University Partnership.

As you observe, only about a third of the funding for the IGY was specifically appropriated for the IGY itself. The remainder came from private institutions and ongoing programs. Nonetheless, the majority of funds ultimately derived from government sources. Thus, I do not believe that cost alone is a valid criterion for allocating funds between federal in-house programs and non-governmental entities.

The diversity of funding sources and institutional settings that has been a hallmark of U.S. scientific research is, in my view, a great strength. Good ideas usually find a fertile seedbed somewhere in our diverse system. The federal laboratories, with a depth of expertise and infrastructure, well suited to carrying out extended, resource-intensive projects. The universities provide innovation, imagination, and flexibility. They serve not only as the indispensable training ground for new generations of scientists, but also as the seedbed for new ideas. We must maintain the strength of our federal-university partnership in research.

Indeed, the universities have already demonstrated their responsiveness to the challenge of the global change problems. For example, Harvard and Pennsylvania State have reorganized their earth science activities to stress interdisciplinary efforts.

There are, however, some grounds for concern about the infrastructure and resources available to the universities. In times of budget pressures, federal support for external research is bound to be vulnerable to budget cuts. But universities, like other research institutions, cannot function effectively in a stop-start environment. Reasonable stability in funding is essential for effective use of our academic community resources. The projections of continuing increases in National Science Foundation budgets are most heartening, and merit strong support from the Congress.

The infrastructure for research at universities also requires attention. Improvement in instrumentation has long been a concern, and a number of budget initiatives have been proposed. The IGBP will pose new challenges because of the vast amount of data that will be generated. How will the universities gain access to this data stream? We are just beginning to grapple with this question, but it is unlikely to be answered without significant new resources for communications and computing at the universities.

In sum, the non-government research sector is more capable today than in 1957. However, the challenges posed by the IGBP are immensely greater than those of the IGY and will demand greater resources.

Thank you again for providing me with an opportunity to elaborate on my remarks at the July 16 hearing, and to respond to your very pertinent questions.

Yours sincerely,

FRANK PRESS, *President.*

Senator GORE. Our next witness is Dr. Berrien Moore, director of the Institute for the Study of Earth, Oceans and Space at the Science Engineering Research Building at the University of New Hampshire in Durham, New Hampshire. I am always delighted to see a witness from New Hampshire.

Dr. MOORE. We are always delighted to see you in New Hampshire.

Senator GORE. Thank you.

We have two other witnesses who are natives of New Hampshire today. I asked the staff what they had in mind here, but in fact we are pleased to note that the best work being done in this area is at your institute, and we appreciate the leadership you all have provided very much, Dr. Moore.

And we invite you to present your statement. The complete text will be put in the record, if you would summarize it. But proceed as you see fit.

STATEMENT OF DR. BERRIEN MOORE, DIRECTOR, INSTITUTE FOR THE STUDY OF EARTH, OCEANS, AND SPACE, UNIVERSITY OF NEW HAMPSHIRE

Dr. MOORE. Fine. Thank you.

One thing, Senator Gore. I have a few viewgraphs that I would like to show.

Senator GORE. Good.

Dr. MOORE. Will it be necessary to be using the microphone or would I have someone else show the viewgraphs?

Senator GORE. This is not an argument in support of contra aid, is it?

Please go ahead. We can turn the lights down in here. You might actually turn that screen a little bit so the folks sitting out there can also see it, and I will move over here.

Dr. MOORE. Senator Gore, what I would like to do is just submit my written testimony and adjust my remarks to the conversation of this morning. I would like to gauge the remarks in two ways: first, to speak briefly about the CFCs and the issues that you raised regarding action; and then secondly, to try to talk about the underlying scientific problems that were faced that go beyond the CFC issue.

In a sense the CFCs may be the good news. It is a relatively straightforward problem. We think we understand the causes and the effects, and the elimination of the production term is not that difficult by comparison to questions associated with the carbon dioxide, release of methane or the release of nitrous oxides.

For instance, when one burns 100 pounds of gasoline in your gas tank, you produce 300 pounds of carbon dioxide. So, the traditional techniques of scrubbing are just inappropriate.

Senator GORE. Now, wait a minute. Give me those numbers again.

Dr. MOORE. When you burn 100 pounds of gasoline——

Senator GORE. Yes.

Dr. MOORE [continuing]. You produce 300 pounds of carbon dioxide.

Senator GORE. Wait a minute. I need a remedial scientific course here. Doesn't that violate some law of physics?

Dr. MOORE. No. What you are forgetting about is one of the parts in the puzzle is the oxygen.

Senator GORE. Okay, I got you now. Thank you.

Dr. MOORE. You're combining.

The basic point is that it is an extremely difficult problem to go around scrubbing. And in fact, you would probably take as much

energy to try to scrub the CO_2 out of the system as you would have gained by burning the fossil fuel to begin with.

So, I agree in a sense with your call for action with respect to CFCs. I agree with your call for action on CO_2, but I believe that we need to distinguish between something like the CFC issue, which is a totally manmade chemical, and something like the CO_2 question. In fact, the CO_2 is really just a metaphor for large-scale changes in the metabolic system of the planet, the entire biogeochemical spectrum of the planet.

And to continue metaphorically for just a moment, we can think of the earth as a chemical plant, and the chemical plant is contained inside a big building that provides the heating and cooling system for the chemical plant. And the tricky thing is that the function of the chemical plant affects the heating and cooling system. And the heating and cooling systems affects, in turn, the function of the chemical plant. And that is the systemic problem that we have with this perturbation of the biogeochemical cycles of the planet.

What we have here in figure 1 is the ice core record of CO_2. This is a remarkable record. It is done primarily by the Bern Group in Switzerland, also in Grenoble, and also in Australia. And we have a pre-industrial 1850 value of about 280 parts per million in the atmosphere rising exponentially to a current value of around 350.

Senator GORE. The upturn—I cannot read the dates, but it is around 1750. Is that——

Dr. MOORE. Well, in fact, it goes flat to around 1860. You see a slight rise there, and this is 1850, 1900, 1950, the year 2000. And it really picks up exponentially.

Senator GORE. It's the Industrial Revolution.

Dr. MOORE. Precisely.

That is our historic record. So, there is no question that CO_2 is going up in the atmosphere and that prior to the industrial period, it was relatively constant.

Another thing that we know is that if we go back and look at what was the atmosphere like during the last glaciation, it appears there were about 200 parts per million. So, during the last period of glaciation, we had a very low concentration of CO_2 in the atmosphere. Prior to the Industrial Revolution, it was about 280; currently it is about 350.

This is the Mauna Loa record [fig. 2] that you mentioned earlier. It is one of the most extraordinary pictures in science today. You see two things. You see the oscillation, which is essentially the northern hemisphere's photosynthesizing, taking CO_2 out of the atmosphere, releasing it in the winter with respiration, and then you see the exponential run on top of that, which is essentially the human activity.

Senator GORE. Just to clarify that for those who might be seeing this graph for the first time, the up and down is an annual cycle. And when the cycle goes down, that is when it is spring and summer in the northern hemisphere where a great mass of vegetation is and the deciduous vegetation is absorbing carbon dioxide. And then in the winter, when the leaves fall off, it goes back up.

That graph was the first one that really got me interested in this. It is interesting if you connect the peaks, there is almost—it

may be coincidental. I would be interested in what statisticians would say about it, but there is almost an exact correlation between the pattern of the peaks and the global economic activity in the last few decades. You can see the recession of 1974–1975. You can see world oil consumption going down, and the rate of increase goes down. And then when it picks back up, the CO_2 concentrations go back up.

Dr. MOORE. There is another thing that should be noticed too. Notice right here with respect to the record breaks, that is not a fault of the xerox machine. It essentially when we began to lose the record, policy decisions could have turned this station off and we could have lost this really remarkable record. So, the importance of these long-term records is absolutely invaluable even in light of the imperative questions that we are facing today.

Senator GORE. Yes.

Dr. MOORE. Let me just speak for a second about this and see if I can capture some of the complexity about the carbon dioxide problem.

We know another thing, and that is that the rate of deforestation is—and this is the conservative estimate, that the clearing of closed-canopy, tropical forests for permanent agriculture is between 70,000 and 100,000 square kilometers per year. The State of Tennessee measures roughly 100,000 square kilometers.

Senator GORE. So, we lose tropical rain forests at the rate of one Tennessee per year.

Dr. MOORE. That is right. And I stated the conservative calculation. That is the clearing of closed-canopy, tropical forests for permanent agriculture. That does not include slash and burn. It does not include the conversion of grasslands and savannas or shrubland and woodlands.

Senator GORE. At that rate, when will the tropical rain forest be completely gone?

Dr. MOORE. Let me give you a slightly different answer.

Senator GORE. Fine.

Dr. MOORE. At that rate in 30 years we will have cleared an area the size of India. And the reason I am cautious is that we do not have a good measure of the extent of the remaining tropical forests that we have today. But in 30 years we would clear an area the size of India.

Senator GORE. Now, if I could interject one other point. There is a common misconception, is there not, that these tropical rain forests are lush because they are in areas that have lots of sunshine and lots of rain, and that leads to a comfortable assumption that even if they are destroyed, they will regenerate if you leave them there. But in fact, the soils are among the least productive in the world.

Dr. MOORE. That is right.

Senator GORE. And the lushness results from millions of years of very complex evolution. And once they are destroyed, they do not come back. Is that correct?

Dr. MOORE. That is correct. These are mainly on volcanic soils. They are nutrient poor, which is one of the complicating feedback mechanisms. The reason that these areas have been cleared year after year is because they are essentially using them up.

Senator GORE. Now, again, the reason why it relates to this graph is, as everyone can see, the annual cycle is quite large because of the capacity of the vegetation to absorb CO_2. If the base of vegetation is diminished dramatically—and a very large portion of it is in rain forests—then that has a very big impact on the concentrations of CO_2 in the upper atmosphere. Correct?

Dr. MOORE. It does because the numbers that we are working with are large. But it would be incorrect for me to say that if we reforested the world, that we could solve this problem. There are roughly 600 billion metric tons of carbon in living vegetation. And there are roughly 750 billion metric tons in the atmosphere [fig. 3].

Senator GORE. Give me those numbers again.

Dr. MOORE. There are roughly 600 billion metric tons of carbon in living vegetation and about 750 in the atmosphere. So, there is more carbon dioxide in the atmosphere even though it is in parts per million than there is in living vegetation. Of course, there is probably twice to three times that much in soils of the world.

And what this really means is it is a contributor to the fossil fuel burden.

Senator GORE. What is the ratio in the atmosphere and in the biota? I just lost your numbers.

Dr. MOORE. What we have right here. This is missing a zero. It got blotted out. But roughly there are 500 billion to 600 billion metric tons in living vegetation.

Senator GORE. That's 500 billion to 600 billion.

Dr. MOORE. Billion metric tons. And about 740 in the atmosphere.

Senator GORE. Is that 740 metric tons?

Dr. MOORE. Billion.

Senator GORE. So, 740 billion.

Dr. MOORE. Billion metric tons.

Senator GORE. And 500 billion to 600 billion?

Dr. MOORE. In the biota of the terrestrial vegetation and about twice that in the soils, in the upper layer of the soils.

Senator GORE. So, they are roughly comparable, but there is more in the atmosphere.

Dr. MOORE. That is right.

Senator GORE. All right.

Dr. MOORE. But the important aspect is that the deforestation term is running currently at about 20 to 30 percent of the fossil fuel term. So, it is this, as you said accurately earlier——

Senator GORE. What does that mean? What do you mean the term is running?

Dr. MOORE. Currently we are producing about 5 billion to 6 billion metric tons per year CO_2, carbon dioxide, by the burning of fossil fuels. We are producing about 1 billion to 2 billion metric tons. So, that would be 20 to 40 percent of the 5 by the deforestation. And if you add those together, you get the total anthropogenic change curve.

Senator GORE. All right, now wait a minute. The 1 to 2 billion metric tons is amount that is put into the atmosphere due to decay and burning?

Dr. MOORE. That is correct. It is not the normal cycle of photosynthesis and respiration that is going on. This is the——

Senator GORE. This is the extra amount which comes from deforestation. Well, now hold on a second.

That results in a reduction of the capacity of vegetation to absorb carbon dioxide as well. If 20 percent of the CO_2 comes from the actual destruction of the wood and pulp, then what additional percentage comes from a reduction in absorption?

Dr. MOORE. This gets very complicated, Senator. The number that I am giving you is essentially the net number. It is not the gross number. It is the difference between regrowth and recovery—for instance, as we have had in New England where essentially it was deforested 70 years ago—against the oxidation of the biomass burning that occurs in the tropics. That is it the net number that I am giving you.

Senator GORE. Okay, 20 percent.

Dr. MOORE. Yes, 20 percent.

Now, one of the great difficulties in this though is that if we take those two terms, the amount of fossil fuel that we are burning and the amount that is being cleared by vegetation, and we look at their historical patterns, it turns out that the deforestation term has a different picture. It does not have quite the same rapid ramp from the industrial revolution. The deforestation term is at about 60 to 70 percent of the fossil fuel term; that is to say, mankind's changing of the carbon cycle is 60 percent more than just the fossil fuel term. It is 60 to 70 percent more than just that.

The difficulty with this is that if we take our best understanding of the oceans, and we hook our best understanding of the oceans, which is where the CO_2 goes—it does not build up in the atmosphere—the system does not balance. The equations do not work. This does not give us what we believe to be true.

Some people have argued, Senator, that perhaps the deforestation is an artifact. It does not hold up under hard analysis. So, I will speak just quickly scientifically in another light.

Geochemists have been very clever using isotopes to try to do some of these calculations. It is an inverse method. They look at some pattern of isotopes and they infer what might have happened. One of the carbon isotopes is C_{13}. It is not radioactive. It does not decay. C_{13} is just slightly heavier than normal carbon in CO_2. There is not much in the atmosphere, but we know pretty well what is there. Vegetation discriminates against C_{13}. So, it is depleted in C_{13}. Therefore, fossil fuel is depleted in C_{13}.

Now, the thing that is particularly interesting is that we think we have a good record of fossil fuel combustion. We think we know that very well. And we think we have a pretty good record now with the ice core data of what the C_{13} CO_2 has been in the atmosphere. There is a certain dilution. When you burn fossil fuel, there is not much C_{13} in it because the vegetation discriminated against it. So, you dilute the atmosphere with C_{13} when you burn fossil fuel.

There is not enough dilution going on. In fact, the numbers are almost exactly what the deforestation numbers, when we do a direct calculation show us; that is, 60 to 70 percent must be coming in from biomass burning through deforestation. So, two lines of evidence lead us to this conclusion, and it is a very important conclu-

sion because it says essentially we do not know how the carbon cycle works.

And it just isn't the oxidation term. The world is a really interesting place when we view it through the lens of carbon. We live in an oxygen rich world unfortunately. And therefore, most of the return of organic material, most of the carbon return, is through oxidation, kind of a back door, you might say. Return for organic carbon-rich material is through reduction, through the production of methane.

What I have put up here is the ice core record of methane. Ten thousand years before present, coming up to 200 years before present, essentially a steady state, flat. Methane in the ice cores—almost straight growth [fig. 4].

Senator GORE. And you see that as caused by industrial civilization also.

Dr. MOORE. Yes.

This is an article that just appeared in the *Journal of Atmospheric Chemistry,* a Dutch journal [fig. 5].

Senator GORE. I missed that.

Dr. MOORE. And this has just come out. I was in Stockholm three days ago, so you would not have been able to see it. It has just come out.

The extraordinary thing—this is methane in the atmosphere in parts per billion. It is going up. It has been going up at about a percent——

Senator GORE. What are the dates on the bottom?

Dr. MOORE. They are 1981, 1982, 1983, 1984.

Senator GORE. Okay.

Dr. MOORE. This is the Tasmanian station in the southern hemisphere.

And for the first time we see the rate of increase seems to be changing and actually slowing. We have no idea why methane was really going up in the first place. We have even less idea why it would change what it has been doing. And that is the reason I think, Senator, it is extremely important that we recognize that what we have is global change that is extremely complex.

Senator GORE. Yes.

Dr. MOORE. And it isn't just methane. And methane, as you commented earlier, is extremely important because it is roughly 30 times more effective in blocking outgoing radiation. So, it is essentially 30 times more efficient as a greenhouse gas than CO_2.

This was something that you mentioned [fig. 6]. These are the pieces of a greenhouse warming, how much is due to carbon dioxide, how much is due to CFCs, methane, nitrous oxide and ozone. This one we can do something about. This one we think we are really beginning to understand. You see that really requires a bulk of it. However, that does not get away from the fact that these others are beginning to come on-line.

And the last one I wanted to show—this is N_2O emissions [fig. 7]. This is extremely complicated because it is part of the greenhouse gas and it actually interacts with the methane cycle. So, it is not just CO_2. It isn't just CFCs. It is not just carbon. But it is carbon, nitrogen, sulfur, phosphorus. And it is not just the biogeochemistry; it is the climate itself.

I will return to my written testimony—just a few remarks.

I think you are correct. And in fact, I think one of the most important things that we now understand is that the anticipated change of these global changes will take climate and our natural environment outside the range of historic experience. There is nothing comparable in the last 100,000 years. We must begin now to try to understand in order to take informed action.

The challenge requires a new perspective on earth science transcending traditional disciplinary boundaries. It requires understanding how the earth functions as an entire system. It requires a global view exploiting the unique opportunities for observing earth from space. It requires a program of long-term observation, of an integrated information system. It requires a new approach for setting priorities within Federal agencies.

In particular, it requires the development of international understandings not only on the nature of the challenge, but also on the scientific approach to address it. On a very practical level, more effective and less constrained measures must be implemented to allow a more free exchange of scientists and of data.

Lastly and above all, it requires a commitment at the highest levels to a program which will address these concerns in a farseeing and coherent manner.

The challenge is staggering. Nonetheless, we have no greater concern than the future of this planet and a life upon it. We owe it to the next generation that already dwells among us.

For my daughter and our children, I thank you for your consideration.

[The figures referred to follow:]

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Figure 1.—Atmospheric CO_2 concentrations measured in glacier ice formed during the last 200 years.

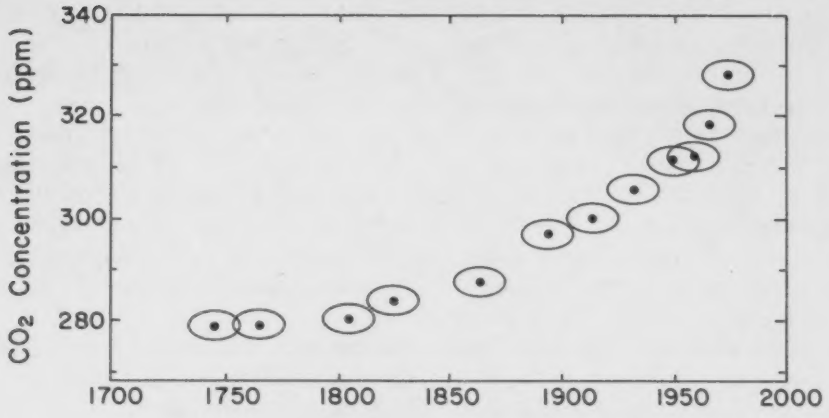


Figure 2.—Concentration of atmospheric CO_2 at Mauna Loa Observatory, Hawaii. Dots indicate monthly averages determined from continuous measurements.

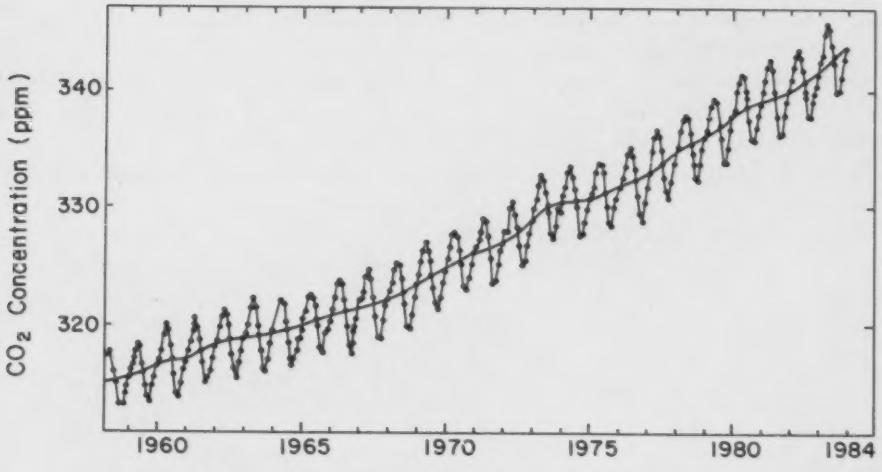


Figure 3

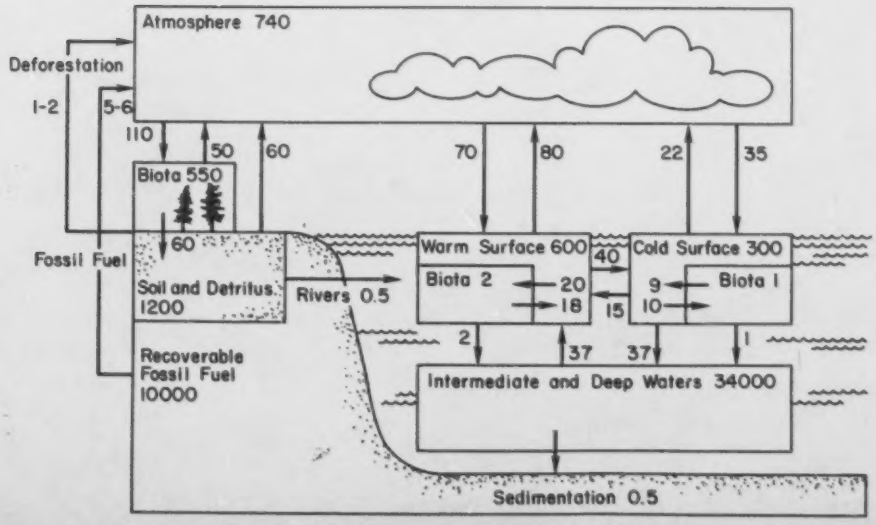


Figure 4.—CH_4 mixing ratios measured in air trapped in ice as function of time.

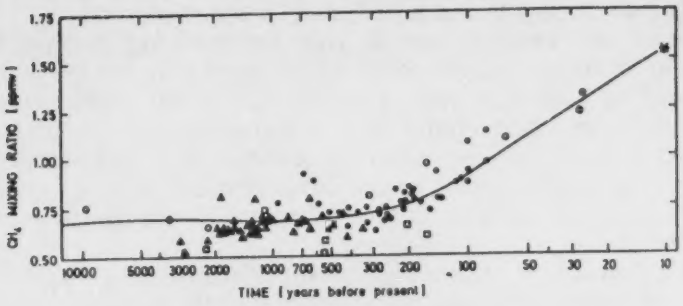


Figure 5.—The 12-month running mean CH_4 concentrations (□) at Cape Grim, Tasmania covering the period September 1980 to December 1984 inclusive.

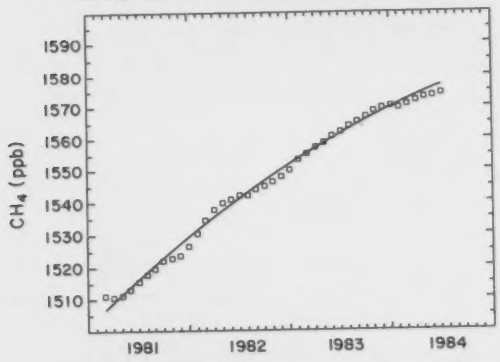


Figure 6.—Cumulative equilibrium surface temperature warming due to increase in carbon dioxide and other trace gases from 1980 to 2030 as computed by a one-dimensional model.

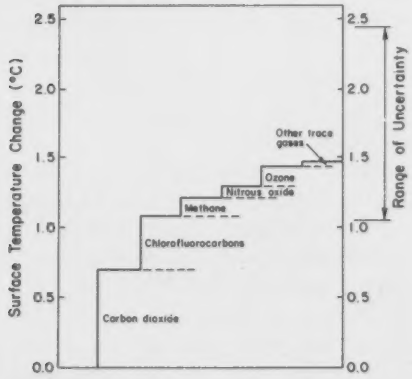
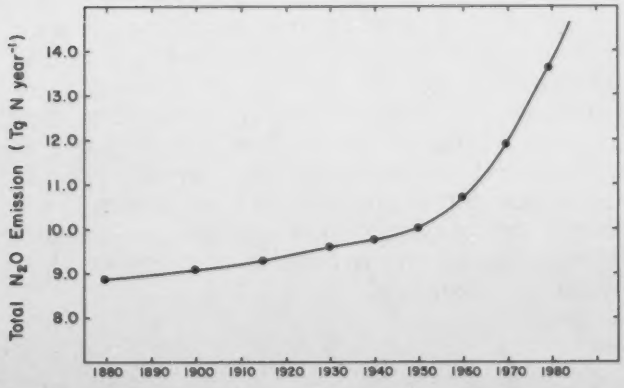


Figure 7.—Trend of estimated total N_2O emmission rates between 1880 and 1980.



Senator GORE. Thank you, Dr. Moore. Your testimony is very interesting. It challenges all of us to try to keep up with you. Some of these facts you presented are difficult to comprehend.

But one of the central points you are making is that this phenomenon is extremely complicated involving a lot of interrelated factors. And as I said in my opening statement, there seems to be an impressive new consensus in the scientific community that the greenhouse effect, the depletion of ozone, the destruction of rain forests and other phenomena are intertwined. And in order to understand them and deal with them, we must see them as a unified whole set of changes.

But the cumulative impact is extremely harmful. And if the scientific consensus turns out to be correct, they will result in dramatic and very harmful changes to the world environment, changes which may have already begun.

Now, you pointed out that some of the factors are less complex than others and, therefore, presumably easier to deal with. You used the two examples of chlorofluorocarbons, on the one hand, and carbon dioxide on the other.

I agree with that. And again, as I attempted to do with Dr. Press, let me translate what you are saying into terms that I can deal with in the public policy environment. It is obviously unthinkable that we would have a dramatic change in the near term in our use of fossil fuels. Anyone who paints the greenhouse effect as merely the consequence of the burning of fossil fuels is led quickly to the conclusion that there is nothing we can do to stop these environmental changes because the solution is unthinkable.

We could take, however, a very different approach. We could take those aspects of the problem which we know we can deal with and begin now to phase out the production of chlorofluorocarbons, to stop the destruction worldwide of one Tennessee's worth of rain forests every single year, and simultaneously dramatically increase our scientific efforts to improve the base of knowledge upon which further actions can be based.

If we simultaneously improved our understanding of the problem and built our confidence by taking on those aspects of the problem, which ought to be addressed for other reasons anyway. Other solutions then might come within our reach, such as more effective ways to conserve energy and more effective efforts to produce alternatives to fossil fuels in the next century.

And so, I think that we are really faced with a basic choice at the threshold. Are we going to try to do something about this or not? Are we going to recognize that action is possible, or are we going to retreat and acquiesce in the continued destruction of ozone, destruction of rain forests and catastrophic modification of the global environment over the next century?

I mean, I think that people at the grassroots level confronted with the choices involved would clearly come to a conclusion that we ought to do something about it. It is complicated vastly by the need for international cooperation and by the scale of changes needed. But that should not prevent us from acting.

Now, let me ask you a couple of scientific questions that I do not understand. What caused the dramatic upsurge in the appearance of methane in the atmosphere?

Dr. MOORE. It is frightening. We really do not know.

One of the things that is extremely important to keep in mind always is that methane was always being released historically from the earth to the atmosphere. But it was remarkably stable. So, something different is happening.

With the destruction of tropical forests, we are essentially putting a lot more organic material in wet, oxygen- poor places that will come out as methane. We may be beginning to see a warming in high latitudes, in arctic areas and some of the peat bogs maybe releasing trapped organic material as methane.

Senator GORE. And ice?

Dr. MOORE. And ice.

We know we are producing some methane with natural gas flaring in the anaerobic zone of the fire. So, it may well be the cumulative effect of many of these things.

The ones that are most disturbing to me, as I look at it, are the fact that it is tied in with the organic material that is coming out of deforestation, the fact that it perhaps is an indication of some warming trends in high latitudes. And the third area is that methane, as opposed to CO_2, is active in the atmosphere. And it may well be that the reason it is building up is because some of the sinks have become less effective primarily due to urban pollution.

Senator GORE. All right. Let me translate that if I can. You talked about higher——

Dr. MOORE. I am sure you can.

Senator GORE [continuing]. Warming in higher latitudes. One of the basic facts about a global warming is that it does not occur evenly across the face of the globe. If we have a temperature increase of 2 degrees, there may be an increase of only a fraction of a degree at the equator, but an increase of 8 or 9 or 10 degrees at each of the poles.

Dr. MOORE. That is correct.

Senator GORE. Correct?

Dr. MOORE. That is correct.

Senator GORE. And if we have an average increase of 4 degrees, which the scientific consensus says we are headed toward, then that means the temperature at the poles may increase 12 to 15 degrees. Correct?

Dr. MOORE. That's correct.

Senator GORE. Now, the last ice age was accompanied by a decrease of about 4 degrees worldwide. So, a temperature change on that scale is very significant for the global environment.

And so, what you are saying is that parts of the earth's surface, land and water, which have in the past absorbed large amounts of methane, as they become warmed by global atmospheric change, they may release that into the environment, thus accelerating the process which caused the release. Is that right?

Dr. MOORE. That's correct.

Senator GORE. I saw a story recently—I would like you to interpret it for me—about white plumes being sighted in the arctic region. Do you know the story I am familiar with that the scientists identified as methane venting into the atmosphere from ice that was warmed?

Dr. MOORE. I am not familiar with it. I have heard essentially the same, and I do not have any of the details myself.

Senator GORE. We will ask the NOAA witness who is going to be testifying. And someone from staff is going to get that news report.

Your testimony, Dr. Moore, cites a scientist from MIT, Dr. Kerry Emanuel——

Dr. MOORE. Yes.

Senator GORE [continuing]. Who has produced a study showing the effect of a 2 to 3 degree increase on weather systems and has predicted a 50 percent increase in the power of hurricanes. Is that in your prepared statement?

Dr. MOORE. Yes, it is.

And if I could, I would like to take just a minute to remark about not only this study, which looks at a warming trend and a change in ocean circulation associated with greenhouse warming that could lead to perhaps a 50 percent increase in hurricane power, but how the oceans circulate is critical in terms of the effectiveness of the uptake of the oceans of CO_2, how fast they take CO_2 out of the atmosphere.

If we get a change, as you have just described, with the warming in the polar regions and not much change in the tropics, we are going to take some of the gradient. Some of the difference between polar regions and low latitudes—that is in the tropics—will remove some of that difference by warming the polar regions and not changing the tropics.

That could have an influence upon ocean circulation and in particular how fast the oceans turn over. Some studies would indicate that it would slow down the turning over of the ocean, the circulation in the vertical. That would slow down the ability of the ocean to take up CO_2 which feeds back to saying CO_2 will increase faster in the atmosphere.

The response of the ocean and climate change is a very serious consequence.

Senator GORE. And has been identified as one of the two largest uncertainties, the cloud system being the other. Correct?

Dr. MOORE. That is correct.

Senator GORE. Now, just to summarize what you are saying there, the oceans contain a large amount of carbon dioxide.

Dr. MOORE. That is correct.

Senator GORE. Scientists have been divided on an important question. As the atmosphere warms, will that increase the ability of oceans to absorb carbon dioxide, or will it decrease their ability to absorb carbon dioxide? And third, could it possibly lead to a disgorging of carbon dioxide presently trapped in ocean sinks? Correct?

Dr. MOORE. That is correct.

Senator GORE. Now, am I correct in saying that the trend in the scientific community has been a rather pronounced trend toward a consensus that warming will reduce the ability of oceans to absorb CO_2. Is that right or wrong?

Dr. MOORE. Trends are difficult to ascertain. But speaking personally, I would agree with you.

Senator GORE. Okay.

Now, on weather systems, the Emanuel study that I cited, the world's weather system is, in part, an engine for transferring heat from the equator to the poles and cold air from the poles toward the equator. What you were saying earlier is if you change the ratio of temperature at the equator to temperature at the poles, then you change the equilibrium in the world's weather system rather significantly. Is that right?

Dr. MOORE. Precisely. That was the point I was trying to make.

Senator GORE. All right. What was your reaction to my exchange with Dr. Press about the long period of time necessary for this study that is being organized worldwide?

Dr. MOORE. Actually, Senator Gore, I thought that your comments to me were so well-reasoned, and I thought they were with Dr. Press also, and his reply that there are actions that could be taken now that do two things. They take actions in important areas about which we have relatively little uncertainty. They also are somewhat like deciding on the shape of the conference table. Once you are able to take an action, it becomes easier to take the second action.

And secondly, information is being accumulated now, and it will be next year and the year thereafter. So, we are not going to ask for putting on hold all action until the 21st Century.

But I think your comments in terms of the importance of action now and the sequential importance of the scientific program are so well-reasoned, I do not know why they are not happening.

Senator GORE. Well, that's a good note to end your testimony on.

And I appreciate your appearance here. And I hope you take good memories of it back to New Hampshire with you.

Seriously, thank you very much for the work you are doing and for your testimony here. Thank you.

Dr. MOORE. Thank you, Senator Gore.

[The statement follows:]

STATEMENT OF DR. BERRIEN MOORE, III, DIRECTOR, INSTITUTE FOR THE STUDY OF EARTH, OCEANS, AND SPACE, UNIVERSITY OF NEW HAMPSHIRE

Mr. Chairman, thank you for the opportunity to testify today on the subject of Global Change. I cannot cite another more compelling subject with which the scientific community must grapple, if only because we believe it will alter the world as we know it so substantially, and affect the very future of this nation, as well as all others.

My name is Berrien Moore III, Director of the Institute for the Study of Earth, Oceans and Space. The Institute is a graduate research and teaching facility within the University of New Hampshire. As the name implies, the Institute is focussed upon the earth and space sciences. We depend upon the support of NSF, NASA, and NOAA, and other Federal and state agencies. Therefore, we have an undeniable self-interest in these proceedings, and I believe it only fair to state that for the record at the outset.

My testimony, however, is based upon concerns which I have that go far beyond those that are of a consequence to the financial health of our Institute. I am a past member of the Space and Earth Sciences Advisory Committee of NASA, a past member of the Committee for Earth Sciences of the Space Sciences Board, a member of the Earth System Science Committee of the NASA Advisory Council, and I recently have been appointed to the National Research Council Committee on Global Change. As a consequence, I am close to many of the issues being discussed here today, but I want to emphasize that I am speaking from my own point of view rather than as a spokesman for any of these groups.

The Earth has always been a dynamic, changing place. This has been true since the beginning; it has been particularly true because of the presence of life. During the last 4.5 billion years that life has evolved, these biological processes have fundamentally modified the planet--particularly the chemistry of the Earth's hydrosphere, lithosphere and atmosphere. Early life forms developed oxygenic photosynthesis and thus created an oxygen-rich atmosphere that was hospitable to the evolution of land plants, animals and finally, humans. And now human activities appear to hold the potential for future planetary change. In an extraordinarily short period of time, we have altered the structure of vegetation and soils, shifted great stores of chemical resources, consumed large quantities of fossil fuels, and introduced new combinations of organic and inorganic compounds into the Earth system.

The geologic record provides evidence of other biogenic changes in the past epochs. However, in a critically important temporal sense, the influence of humans is fundamentally different from other factors that have shaped the Earth: the rates of change tend to be far greater than those of other evolutionary processes. This is a fundamental difference for the Earth and for us.

For instance, it is now common knowledge that critical integrative features of the Earth, such as the concentrations of "greenhouse" gases like carbon dioxide and methane, have moved well-outside their historical range: if the present trend continues, it will lead to a doubling of the carbon dioxide in the atmosphere near the middle of the next century.

Carbon dioxide, methane and other "greenhouse" gases act like a blanket (or a pane of glass in the atmosphere) to warm the earth. Incoming rays of the sun reach the Earth's surface unimpeded, but the outgoing longer wavelength radiation is absorbed by these radiatively important gases in the atmosphere. Changes in their concentrations will likely lead to changes in the heat balance for the entire system.

Our best computer models predict that the impact of doubling atmospheric carbon dioxide would be a global warming of 2 to 3 degrees Celsius (or 3 to 5 degrees Fahrenheit) with about three times that magnitude in the polar latitudes. And increases in other greenhouse gases such as methane, chlorofluorocarbons, and nitrous oxide, could double the greenhouse effect.

Methane -- some may recognize it as marsh gas -- is increasing even faster than carbon dioxide (over 1.1% per year during the last decade). We are uncertain as to the cause. We suspect that the increase is associated with the expansion in area and productivity of rice paddies during the green revolution as well as the change in the rate of natural gas production. Another candidate is the lowly termite. Ideal habitat for termites is provided under savannah conditions in the warm latitudes, and savannah conditions are being unwittingly produced at a prodigious rate by the massive deforestation occurring in the tropical regions. There may be as many as 3/4 of a ton of termites per capita on the Earth today, and they may be responsible for as much as ten percent of the methane produced. Another suspected source is the release of methane from frozen peatlands due to melting of the permafrost in the Arctic as the earth warms. And another possibility is the competition from urban air pollution in the chemistry of the hydroxyl radical, which provides the primary mechanism for removing methane from the atmosphere. Together with fluorocarbons and nitrous oxide, the effects of these other greenhouse gases are expected to be comparable and additive to those of carbon dioxide.

There are unexplained variations in ozone, particularly over Antarctica. Forests in the industrialized world are declining -- a particular example is the red spruce in New England. It is believed that this is tied to acid rain, but it may be connected to alterations in ozone or other independent or compounding phenomena.

In the tropics the current rate of deforestation -- the conversion of closed canopy tropical forests to agricultural land -- is between 70,000 to 100,000 square kilometers per year. This area roughly equals the size of the state of Tennessee; and it roughly equals the combined area of Massachusetts, New Hampshire, and Vermont, which is approximately 70,000 square kilometers. Destruction of our forests at this rate over thirty years would equal an area roughly the size of India. But why is this important? By integrating the knowledge of the biologists and ecologists with that of the oceanographers and atmospheric scientists, we have discovered a startling fact: changing patterns of vegetation feed back into the global biogeochemical processes, which in turn determine the climate.

We are uncertain as to all the effects of the deforestation and pollution. The effect we hear about most frequently is the loss of species with the gene pool being degraded. Diversity of species is necessary for the normal functioning of ecosystems and the biosphere as a whole. The genetic material in wild species contributes billions of dollars yearly to the world economy in the form of improved crop species, new drugs and medicines, and chemicals and other raw materials for industry. But an additional effect we have only recently recognized is that this extensive reduction in biota affects regional rainfall as well as the carbon dioxide concentration of the globe.

Continuing the trail of carbon dioxide, we believe that currently the oceans take up about 2 to 3 billion metric tons of atmospheric carbon dioxide per year, about half as much as is released to the atmosphere in the combustion of fossil fuels. But we are not yet confident in this estimate, and we are far less certain about what the oceans might do in the future given a warming of the planet.

One aspect of an inevitable rise in ocean temperatures is being explored by the atmospheric science community. Serious thought is being given to the prospect that more powerful and destructive tropical storms may be spawned by warmer ocean surface temperatures resulting from the greenhouse effect. Based on the modelling work of meteorologist Dr. Kerry Emanuel of the Massachusetts Institute of Technology, it has been proposed that hurricanes, which draw their strength from the heat of the oceans and convert that heat into mechanical energy in the form of strong winds, may become 40-50 percent more destructive if we were to experience ocean temperature increases of 2 to 3 degrees Celsius. Now, it has been stated by various scientists in our community many times that our modelling efforts require a great deal more refinement. However, given what we do know about the dynamic between the oceans and the atmosphere, the projections regarding tropical storms are certainly plausible, and are regarded as such by no less a figure than Dr. Richard Anthes, Director of the National Center for Atmospheric Research.

Another aspect of global warming is the inexorable melting of the polar icecaps, producing a rising of the sea, which would be combined with the thermal expansion of the ocean in a warmer climate. Conservative projections suggest that the reduction of the icecaps and thermal expansion could yield a sea level rise of more than a meter. This development will eventually alter or inundate barrier islands, alter the saline balance in, and then inundate, coastal estuaries, and threaten the coastal plains. Decades from now, the melting polar icecaps could inundate most known seaports. An interesting statistic frequently cited in coastal environmental, scientific and governmental literature takes on a different meaning in light of this: by the year 2000 it is expected that 80 percent of the US population will live within 75 miles of the ocean or Great Lakes. And not being an expert in national security matters, I will only recommend for your consideration the strategic implications of a more ice-free Arctic Ocean.

While this is far from being well-understood and perhaps rather distant in time, we do foresee more immediate and somewhat better resolved associated changes from a global warming in temperature and rainfall patterns. These changes could well be the most profound: changes in moisture content in soils, with some regions becoming drier, some becoming wetter, producing commensurate alterations in groundwater and aquifer recharge rates in conjunction with the changes in precipitation patterns, will undoubtedly have an important effect on areas we presently accept as agriculturally productive.

Our present mode of living, our industrial society, our economic foundation, are based upon past experience with this environment -- this climate, these soils, this vegetation. We have learned to expect typical weather and seasons, with day-to-day and year-to-year fluctuations, but nonetheless holding a definite perception of what is normal.

We anticipate now, however, that these global changes will take climate and our natural environment outside the range of historical experience. There is nothing comparable in the last 100,000 years. New definitions of normality will be required, new adaptations, and new recognition of fundamental constraints. Our children and grandchildren will have to adjust their expectations of floods and droughts, alter their supplies of food and water, and cope with new realities. Some of these changes may be beneficial; some may be harmful, and others of no particular consequence. However, unless they are perceived and understood in a timely manner, adjustment will almost certainly be painful. We must begin now to lay the foundations of knowledge and understanding for us and our successors to act upon.

This challenge requires a new perspective on Earth Science, transcending traditional disciplinary boundaries.

It requires understanding how the Earth functions as an entire system, concentrating as much on the interactions between the atmosphere, oceans, rocks and ice and the biological subsystems, as on the phenomena within them, and revealing the relations between processes that occur on quite different timescales.

It requires a global view, exploiting the unique opportunities for observing Earth processes from space in close coordination with other approaches.

It requires a program of long term observations, both in situ and from space, to document the changes that do occur, and to provide the basis for computer models to anticipate those that may.

It requires an integrated information system, drawing on data from a wide variety of existing operational and research observational systems as well as those still evolving.

It requires a new approach to setting priorities within the Federal agencies, including long term roles and responsibilities. It requires a better working, detailed, understanding of the roles of government, the academic community, and the commercial sector.

It requires the development of international understandings not only on the nature of the challenge, but also on the scientific approach to address it. On a very practical level more effective and less constrained measures must be implemented to allow a more free exchange of scientist and data. The issues are global, their causes are global, and their resolution must be global.

Lastly and above all, it requires a commitment, at the highest levels, to a program which will address these concerns in a farseeing, coherent manner.

There is today in the United States an uncommon convergence and unity in the Earth Sciences. This convergence is reflected, at the Federal level, in the vital cooperation between NASA, NSF, and NOAA; and is highlighted in the recent report of the Earth System Science Committee on the NASA Advisory Council. This report endorses the emerging multi-agency, multidisciplinary, integrative study of the Earth. In fact in June, 1986, this report and the multidisciplinary research it proposes was collectively and enthusiastically endorsed by the heads of NASA, NOAA, and NSF. This convergence is now beginning to be expressed internationally. In September, 1986, the General Assembly of the International Council of Scientific Unions unanimously endorsed the International Geosphere-Biosphere Program: A Study of Global Change.

This widespread scientific support for a new look at the Earth is based not on something proposed by a few, but rather it is the result of a heightened common awareness that scientific issues now confronting us demand a more integrative approach. The scientific disciplines provide the foundation, but upon this foundation an expanded structure must now be constructed. The new structure must focus on the linkages between scientific disciplines and on the processes that effect and control our dynamic, yet delicate, planet. This unprecedented approach will allow us to understand more clearly the issues that confront humankind.

The challenge is staggering. Much is already happening, thanks to the vision and persistence of concerned individuals. However, the sustained, multi-decadal commitment necessary, marshalling scarce resources on a global level, is almost overwhelming. Nonetheless, we have no greater concern than the future of this planet and the life upon it. We owe it to the next generation that already dwells among us.

For my daughter, and our children, I thank you for your consideration.

[The following information was subsequently received for the record:]

QUESTIONS OF THE CHAIRMAN AND THE ANSWERS

Question 1. Last Saturday, the world population passed the 5 billion mark and population growth trends show no evidence of slowing.

Aren't many of the global trends which scientists are examining today linked with the number of people on the planet?

Are carbon dioxide increases, deforestation and reductions in global habitability an inevitable consequence of world population growth?

What attempts have been made to integrate population considerations into the IGBP?

Answer 1. Certainly, there is a close coupling between population growth and issues of global change, such as the rise of atmospheric CO_2. In fact, the correlation is enhanced if one considers per capita economic activity; therefore, there is a strong tie between global change and total industrial activity, which is partly a function of population size. In fact, as both population and economic activity per capita are increasing, the total industrial pressure on the globe is rising "with the square" or exponentially. There is, in other words, a multiplier effect.

Given the aspirations of many economically poor people, it is unrealistic and cruel to limit their economic growth; therefore, it becomes even more important to stabilize population growth rates. Unless this is done, the problems associated with global change (both their cause and their effect) with increase in severity.

Because of the importance of the forcing terms, such as population growth rate, deforestation, fossil fuel consumption, the IGBP program (as being developed by ICSU) will consider such issues in scenario mode. This rather simplistic approach was adopted (at least for now) in light of the exceedingly difficult scientific issues posed by simply trying to understand the changing chemistry and climate of the planet. However, other investigations that will parallel IGBP and that will focus more upon population and social considerations generally are being launched. For instance, recently there have been meetings in Toronto, at the University of Michigan and at Clark University, that have focused more on the human dimensions of Global Change.

Question 2. What would you identify as the single greatest research need or challenge facing the scientific community with respect to establishing a comprehensive program to study global change?

Answer 2. I see four great challenges (specific rather than general) facing the scientific community:

a. The ability to develop and maintain long data records of highest quality.

b. The ability to manage vast data sets.

c. The ability to develop useful models of the entire Earth system.

d. The ability to train the next generation of Earth scientists.

Comments: Point a. The maintenance of accurate long term data sets is essential and yet given our (both federal and scientific) viewpoint that new and different is better than old and constant, I believe that it will be very difficult to establish and maintain long term, high quality data.

Point b. An essential next-step in the development of IGBP will be the mid-1990's launch of the Earth Observing System (Eos). Effectively managing this data will present enormous challenges, and history does not show that we have been very effective in the past in managing Earth-looking satellite data (other than weather). Putting the data management and information system in place well in advance of launch is critical.

Point c. The IGBP: Global Change has been well received at the concept level by scientist around the globe; however, the task of actually developing an appropriate and consistent scientific program remains before us. It is an enormous task. Observations are essential and there is much to observe, but the IGBP program must be more than an extensive set of observations. Key scientific issues must be addressed and procedures developed, whereby a gradual increase in our knowledge about the dynamics of the global system is obtained and integrated into meaningful and internally consistent views on how the Earth system has evolved, how it functions and how it may be expected to evolve. Global models of the Earth system will need to be developed; this will not be easy nor will it be done quickly.

Although models of the entire Earth system are the ultimate goal, it is important to realize that it is perhaps premature to focus exclusively or even primarily on such models. It rather would be important to develop systematically the different elements which will be required in the gradual development of global models. Even

doing this will require new dollars and thoughtful scientific management, particularly at NSF and NASA. In this regard:

At NSF—The Global Ecosystem Dynamics component within the Global Geosciences Program is particularly important.

At NASA—The Eos initiative and the Interdisciplinary Program (within code EE) are essential to the development of the science of the Earth system.

Point d. The Earth sciences are not alone in facing the difficulty of attracting excellent students (primarily graduate) to the scientific disciplines. This is serious. The "loss" of excellent students to the nonsciences is part of the problem but simply an effect of a deeper more important cause. The underlying "cause" is that we, as a nation, are failing badly in our educational program at all levels. We are becoming a nation of scientific illiterates. The issue is not so much with regard the college students that decide to study history, art, language or any other discipline, but rather the fact that our grade and high school students are generally extremely weak in science and mathematics (eg. see the recent report of Dr. Sally Ride Leadership and America's Future in Space, page 59). It may well be that so many students go into "marketing" because simply they do not know how to make anything themselves.

Question 3. The Earth System Sciences Committee (ESSC) of the NASA Advisory Council and the Office of Science and Technology Policy (OSTP) have made recommendations concerning development of a national strategy to study earth systems. Reports from both groups identified the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA) as key players in such a long-term research plans.

As a scientist and member of the National Research Council's (NRC) Global Change Committee, do you agree with the recommendations of the ESSC and OSTP? Why or why not?

What level of additional funding do you anticipate will be required to support each of the three agency's global change initiatives?

Answer 3. Yes, I agree with these recommendations and as a member of the ESSC, I want to call particular attention to the detailed scientific rationale (The Closer View) that the ESSC is presenting in early 1988. I acknowledge that this is a rather lengthy document; however, it does present the appropriate level of rationale for a program of this importance and cost.

I support the level of funding shown in the ESSC Overview document (pages 44 and 45), though I acknowledge that perhaps the NASA sharp ramp could now be reduced somewhat given increased cost-sharing with the Europeans and Japanese.

Question 4. During Commerce Committee hearings concerning NOAA authorization levels, some concern was expressed that the agency would be unable to fulfill its responsibilities in an interagency research program due to budget limitations.

Do you feel that these concerns are justified? Please explain.

Answer 4. I am not an expert on NOAA's budgetary problems; however, what I believe to be the case is that because of NOAA's position within Commerce and the resulting budget examiner at OMB, the role and importance of NOAA's research program is not appreciated. The role of NOAA in a national Earth science program, however, is essential, and new ways must be developed so that need is more fully recognized (see also pages 40–42 in the ESSC's report Earth System Science: Overview).

Question 5. Your testimony calls for a new approach to setting priorities within Federal agencies.

Do you have any suggestions for creating a more effective method for establishing agency priorities?

Answer 5. I think the Committee on Earth Sciences (CES) within the Federal Coordinating Council for Science, Engineering, and Technology must become more effective. In this regard, it would be useful if there were increased cooperation between CES and the new Committee on Global Change of the National Research Council.

Question 6. As a university researcher, you or your coworkers may have needed to obtain access to data such as satellite observations or meterological data collected by federal agencies.

Have you found that data was readily available in an easily used form?

What suggestions would you offer for developing an integrated information system?

Answer 6. The access to satellite data (of the Earth) has never been very good; the difficulties with LANDSAT and AVHRR are legend. The reason is that NOAA was never given the funds to do the job right. In the future, the Eos program at NASA

and NOAA must be given the lead in the development of an integrated information system for Earth science data. To do it right at least two things are necessary (but not sufficient): long-term funds must be committed well in advance of the launch of Eos and the scientific community must have a large say in the design and in the management of the information system.

Senator GORE. Our final three witnesses will appear as a panel. And I would like to ask them to come to the table at this time. Dr. Robert Corell, Assistant Director for Geosciences with the National Science Foundation; Dr. Leonard Fisk, Associate Administrator with the Office of Space Science and Applications at NASA; and Dr. J. Michael Hall, Director of the Office of Climate and Atmospheric Research at the National Oceanic and Atmospheric Administration, or NOAA as we refer to it over at the Department of Commerce.

I would like to welcome all three of you to the witness table. Your prepared statements will be included in the record in full. We certainly appreciate the work you are doing. We invite you to summarize any portion of your testimony if you wish to. We will begin in the order in which I introduced the witnesses. Dr. Robert Corell with the National Science Foundation, will you please proceed?

STATEMENT OF DR. ROBERT CORELL, ASSISTANT DIRECTOR FOR GEOSCIENCES, NATIONAL SCIENCE FOUNDATION

Dr. CORELL. Thank you. Good morning, Senator.

Senator GORE. Good morning.

Dr. CORELL. It is a delight to be here and to share in this hearing. The scientific stage has been set for those of us from the Federal agencies who are gathered here to share with you our perspectives on how we are addressing these important topics. More importantly we will share with you where we are today and where we are going in the near future.

Senator, we have a short videotape that provides an introduction to the topic that we are here to discuss today. It is about two and a half minutes long. We would appreciate the opportunity to show it.

Senator GORE. Very good.

Dr. CORELL. It is an excerpt from an introduction to the Planet Earth series that played on public TV a few months ago.

[Videotape shown.]

Dr. CORELL. Thank you, Senator, for the opportunity to present that. We thought it would provide a visual context for much of what we have been talking about already this morning.

I thought I might summarize my written testimony around three ideas. First, the context within which we in the Federal agencies and the scientific community are working; secondly, an outline of what I think is a very rich mixture of international, national and agency efforts and plans to implement the research agenda so necessary to address the problems Dr. Moore so graphically outlined. Finally, I would like to describe NSF's plans for a comprehensive research program in the global geosciences.

First, the context. It seems to me that for the first time in history we have the tools, intellectual concepts and insights essential to understanding the far-reaching implications of both the natural processes we have discussed, and more importantly, the man-induced environmental changes that are so evident.

The earth sciences, atmospheric, oceanic, solar, terrestrial and bioenvironmental sciences have evolved and matured dramatically in recent years and are now at a point in their development that a responsible research program on a global scale is within our grasp. We have evolved the theoretical frameworks, the field program methodologies, and a community of research scholars experienced in larger scale, complex research programs.

Further, the technology and measurement capabilities are proven and increasingly available. Proven technologies include satellites to measure environmental parameters on global scales, aircraft, ships and other platforms for *in situ* measurements. Computers from the supergrade to the ubiquitous desk-top computers are available and operational in the scientific community. And new, exciting technologies are evolving which will allow us to address these global scale processes so essential to the understanding of planet earth that we all seek.

In short, the science is much more mature than it has ever been. The technology is increasingly available and in many cases proven, and the scientific manpower has evolved to the stage where we can conduct these exercises.

The second point I would like to address has to do with the evolution over recent years of international, interagency and institutional frameworks and arrangements which will realistically allow us to address these problems. The complex and vital nature of this endeavor with large research implications demands careful planning, priority setting and implementation strategies.

At the Federal level here in the United States science agencies and the scientific community together have already begun to plan and implement global multidisciplinary studies, and in some cases are well along in addressing many of the important issues. The agencies, both singularly and more aggressively in concert, are developing appropriate programs to address those aspects of global change research to which their agencies can contribute.

For example, NSF with the primary responsibility for basic research programs has been very active in sponsoring integrated research programs, while at the same time helping coordinate and sponsor multi-disciplinary and, in many cases, interagency and international research programs that are focused on global issues.

NASA, a partner in this program, has primary responsibility for earth science research missions from space, including mission planning, satellite instrument development and launches.

NOAA, as the principal agency for prediction and information, is expected to continue in that role. We depend upon them to do so and look forward to enhanced programs in climate research and prediction. We look to them for management and distribution of operational real-time data and in many cases the archival data so essential to studying the past for implications about the future.

Other agencies are building global programs: USGS, DOE, DOD, EPA and Agriculture, to mention some obvious ones.

In addition to the interagency arrangements, we have at our disposal a variety of established mechanisms to obtain counsel, advice and interagency coordination. As was mentioned, the National Academy is a key player. I would like to mention that they have recently established a committee on global change, which had its

first meeting only weeks ago. This body will augment the existing boards, committees and panels that so effectively help the National Science Foundation establish our research agenda and set our priorities.

Further, to augment the numerous and well-established interagency committees that assist in planning and implementation of the more specialized aspects of research on global change, the Office of Science and Technology Policy recently established an interagency Committee on Earth Sciences under the umbrella of the Federal Coordinating Council for Science, Engineering and Technology, better known as FCCSET.

This committee has been asked to coordinate Federal efforts with respect to the earth sciences, that is, those sciences that collectively form the environmental sciences, such as atmospheric science, earth science, polar science, ocean science, biological science and so on. We have an array of Federal, interagency and in many cases international mechanisms for coordination and planning of global environmental research.

Let me speak briefly about the international aspects of global change research. Global by definition means we are in the international sphere. No country working alone can make the progress necessary for us to understand in a timely manner how this earth operates. Each country has an important role to play and will share in the benefits of an enhanced understanding of global changes such as those discussed this morning, as well as others that are in the alcoves waiting to be identified.

But, we think the United States is in a very pivotal position and will continue to be so. It is our responsibility to provide a leadership role in the evolution of global change research. The U.S. is already cooperating internationally through both nongovernmental groups such as ICSU—the International Council of Scientific Unions—and through more formal intergovernmental mechanisms, such as the World Meteorological Organization in its world climate program or the Intergovernmental Oceanographic Commission of UNESCO.

ICSU, as was pointed out earlier this morning, has established the International Geosphere Biosphere Program as a scientific approach and a scientific planning mechanism to address global change.

It appears to us that the national and international arrangements are in place that will allow us to get a positive and healthy start; in many cases these mechanisms have been working aggressively over recent years to address the issues of global change.

In fact, with planning well along in many of the components of global change research, we are on the threshold of seeing an integrated national science effort, which brings me to discuss with you briefly what is happening at the National Science Foundation. With your permission, I would like to use two viewgraphs to do that.

Senator GORE. Okay. We need to speed this along if we can, if you can summarize some portions of it.

Dr. CORELL. Just quickly, this chart describes what we at the National Science Foundation are calling the Global Geosciences Programs with a number of programs focused on such things as the

upper atmosphere, global tropospheric chemistry, the biosphere, oceanographic aspects and the solid earth. These are drawn from a complex array of research objectives, many of which were pointed out by Dr. Moore. The chart also shows which agencies contribute to the various subprograms.

My second viewgraph is a cartoon which outlines the specific programs and will serve as a backdrop for our further discussion.

The Global Geoscience Program was formally established in the FY 1987 budget of the National Science Foundation, but in fact, many components were previously operational within NSF. The Foundation's Global Geoscience Program is designed to understand how the planet functions as a system of interrelated processes and to establish the major cause-and-effect relationships within and between the climate system, the biogeochemical cycles and tectonic activities that are operating within the ocean, the atmosphere, the biosphere and the solid earth.

Suggested in this diagram are a number of studies, such as our Global Tropospheric Chemistry Program which addresses processes by which substance of natural or anthropogenic origin enter the atmosphere, are transformed, transported and in many cases are ultimately removed.

The WOCE program is the World Ocean Circulation Experiment, (a remarkable example of international and interagency cooperation), which seeks to study the general circulation of the world's oceans to facilitate a global understanding of the special role that the ocean play in global changes. This program is led by NSF.

TOGA, the Tropical Oceans and Global Atmosphere program, is led by NOAA. We are partners, along with NASA and others. The program will investigate the interannual variability of tropical ocean and global atmospheric systems driven by interest in such issues as the El Nino oceanoghraphic event.

The Global Ocean Flux program identifies and quantifies physical, chemical and biological processes controlling these large-scale biogeochemical cycles and fluxes that were mentioned earlier.

Eventually we must address global ecosystems, and NSF has begun a program to do this called Global Ecosystems Dynamics, using long-term, large-scale observations to examine the role of terrestrial ecosystems in the biosphere, atmosphere, and in the global ocean.

Global Geosciences also includes a program in ridge crest processes which studies the submarine processes of plate tectonics, volcanics, hydrothermal systems, unique biological ecosystems, and the geology and chemistry of the earth's spreading centers.

Further, we are involved in studies of the entire solid earth, trying to seek better understanding of the dynamic processes beneath the earth and within its core, which are the ariving mechanisms for plate tectonics and earth quakes

Studying the earth's archival record in ice sheets is a newer program and will use information from shallow ice cores as well as some rather deep cores. The observations will allow us to better understand past climates on a scale of hundreds of thousands of years.

And finally, the CEDAR program, a program of upper atmosphere studies, will examine the initial stages of coupling between

the sun, and the atmosphere and solar energy transport to the earth.

We see a need for careful planning of these programs, matched by a need for careful data management, and we have put some interagency mechanisms in place to do that.

I would just point out that not all of our global change research at NSF is umbrellaed under the Global Geoscience Program. For example, the international ocean drilling program is a key component in looking at earth records reaching for back in earth's history. It gives us a great deal of information on past climatic processes. In addition, NSF is a major participant in the National Ozone Experiment (NOZE) the second stage of which is about to begin in the next week or two.

These are long-term efforts and will require the commitment of our agency and others to sustain the long-term data-gathering and research programs so essential to these understandings.

In conclusion, Senator, NSF supports the studies of the earth's system. The science agencies working together as partners will continue to respond. We will work as quickly and thoughtfully as possible. NSF will place high priority on those questions that we can address that are central to the issues of interest to this Nation and to our partners in the world, as we seek to wrestle to better understand the world in which we live.

Thank you.

[The statement and questions and answers follow:]

TESTIMONY OF

DR. ROBERT W. CORELL
ASSISTANT DIRECTOR FOR GEOSCIENCES
NATIONAL SCIENCE FOUNDATION

BEFORE THE

SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE
AND NATIONAL OCEAN POLICY STUDY
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

JULY 16, 1987

Mr. Chairman, thank you for the opportunity to testify today on the subject of Global Change Research. Global change is a topic of great importance with which we have all become appropriately concerned.

Berrien Moore has just very effectively shown how our planet Earth is changing, and changing in a way that we do not yet fully understand. He has further demonstrated how research studies focussing on global changes are imperative if we are to protect Earth's envelope of life support in which we and our future generations must live.

Today we stand at the threshold of an unprecedented opportunity to understand the far reaching implications of natural and man-induced environmental changes. A comprehensive study of our planet is within our grasp. The complex and vital nature of this endeavor demands careful deliberation. The federal science agencies and the science community have already begun to plan and implement such a study.

The federal funding agencies (and science community) have simultaneously embarked on a scientific endeavor that has come to be known as the study of "Global Change." It may well be the largest effort in the history of science: an unprecedented study of Planet Earth as a complex system of interacting processes. The agencies, both singularly and in concert are developing programs appropriate to their agency roles, and indeed, through this process the roles are becoming increasingly defined. NSF/GEO has the charge to maintain the health of basic research in all of the earth science disciplines. In addition, NSF has become an active sponsor and coordinator for multi-disciplinary, interagency global research programs which generate and use data from both in-situ field programs, and remotely-sensed data from

earth-looking satellites and from ground-based sensors. NASA's primary responsibility is for earth sciences research missions from space, mission planning, satellite instrument development, and launches. NOAA, as the principal prediction and information agency, is expected to continue it's role in climate research and prediction, and is looked to for the management and distribution of operational, real-time and archival data. NOAA will coordinate with NASA regarding mission planning. Other agencies' plans for global change research are evolving.

Through such respective constituent agency programs as NSF's GLobal Geosciences Program, NASA's Mission to Planet Earth, NOAA's Climate and Global Change Program, and other evolving agency efforts, the United States will remain committed to this formidable effort. The commitment must be sustained over time to create long-term, multi-disciplinary data bases. Nationally the programs need to be invigorated, coordinated and focussed.

At the same time the U.S. has responded to the International Council of Scientific Union's (ICSU) call for an International Geosphere-Biosphere Programme (IGBP) by taking the first step, forming a national Committee on Global Change through the National Research Council. This U.S. committee is being collectively funded by NSF, NASA, NOAA, USGS, the Navy, and DOE, and will provide advice to the agencies and scientific community on how to best formulate and execute a national program in global change.

The agencies continue to work closely together in planning and executing global research programs. Many of the studies are jointly funded between agencies, and will share instruments, ship time, facilities, as well as data generated by in-situ measurements from field programs, from satellites, and from existing data archives.

The Office of Science and Technology Policy recently established an interagency Committee on Earth Sciences under the umbrella of the Federal Coordinating Council for Science, Engineering and Technology (FCCSET). This committee is asked to coordinate the Federal research efforts on earth sciences.

Global change research is necessarily international in scope; the physical and chemical processes which shape and modify our planet are not limited by national boundaries. No country working alone can make the progress necessary for us to understand in a timely manner how the Earth operates. Each country has an important role and will share the benefits of an enhanced understanding of potential environmental change. But the United States is, and will continue to be, the leader in global change research.

The U.S. is already cooperating internationally, through both non-governmental routes, such as ICSU, and through more formal

governmental mechanisms such as the World Meteorological Organization's World Climate Program.

Having set the context of interagency cooperation, I will go on to discuss the National Science Foundation's contribution to global change research, which is known as the NSF Global Geosciences Program.

GLOBAL GEOSCIENCES

NSF has responded to pressing global concerns by selectively and aggressively proposing a major agency-wide, cross-agency, multi-disciplinary thrust called Global Geosciences in the FY 1987 and FY 1988 budgets to Congress.

The central goal of Global Geosciences is:

> To understand how the planet Earth functions as a system of interrelated processes and to establish major cause and effect relationships within and between the climate system, biogeochemical cycles, and tectonic activity operating within the atmosphere, oceans, biosphere, and solid earth.

The rationale for Global Geosciences' focus on global interactive sciences is threefold:

1. Long-term observations of our environment reveal natural and anthropogenic changes in the delicate earth system, some of which may be irreversible and currently have an unpredictable effect. It is imperative to understand the processes contributing to such environmental changes as increasing carbon dioxide and other greenhouse gases, stratospheric ozone depletion, deforestation, and desertification.

2. At the same time, technological advances enable us to measure and observe the Earth better than ever before. Satellites can now monitor certain critical biological, chemical, geological and physical parameters over large spatial scales. However, dedicated research satellites will not be operational for several years. In-situ measurements using high-speed, high-precision instruments provide critical field information, and will provide a future necessary complement to validate and calibrate the cruder but larger scale satellite data.

   Combining remote sensing capabilities with in-situ observations offers the potential for the acquisition of global data sets, and thus make possible for the first time simultaneous pictures of global processes such as ocean and atmospheric circulation, and distribution and densities of ocean and terrestrial biota.

3. State-of-the-art scientific computing allows for computer communications, data management and processing, networking, and sophisticated modeling of earth systems.

Global Geosciences began in FY 1987 and has expanded in its FY 1988 Budget request to Congress to include the following program elements:

Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR)
Global Tropospheric Chemistry Program (GTCP)
Global Ocean Flux Study (GOFS)
World Ocean Circulation Experiment (WOCE)
Tropical Ocean/Global Atmosphere (TOGA)
Global Ecosystem Dynamics
Paleoclimate Studies from Ice Sheets
Ocean Ridge Crest Processes
Solid Earth Studies

(VIEWGRAPH OF FY 1988 GLOBAL GEOSCIENCES PROGRAM)
(VIEWGRAPH OF FY 1988 GLOBAL GEOSCIENCES "CARTOON")

A brief description of each element of the Global Geosciences Program follows:

Global Tropospheric Chemistry: Addresses processes by which substances of natural or anthropogenic origin enter the atmosphere, are transformed, transported by winds, and ultimately removed. Studies distribution and interactions of compounds in the troposphere.

WOCE: (World Ocean Circulation Experiment; NSF lead, with NASA and NOAA.) Studies the general circulation of the global ocean, its average state, and its variability and heat flux in an effort to better predict oceanic forcing, response and feedback to long-term changes in the atmosphere. NSF will fund in-situ oceanographic field programs and model development through the next few years. In the 1991-92 timeframe NASA has launch plans for TOPEX and the NASA Scatterometer instrument on the Navy's NROSS. At this time NSF will intensify its field programs to coordinate specifically with NASA/NAVY ocean satellites, calibrate and validate the satellite data, and use the data to refine the models.

TOGA: (Tropical Oceans and Global Atmosphere; NOAA lead). Will investigate the interannual variability of the tropical ocean-global atmosphere system, its predictability and interactions. TOGA will also develop predictive models. NSF

funds the basic physical oceanography and atmospheric process research that contribute to this program, as well as the modelling efforts. WOCE and TOGA will contribute substantially to each other.

Global Ocean Flux Study: Identifies and quantifies the physical, chemical and biological processes controlling large-scale biogeochemical cycling and fluxes in the open and coastal oceans and at their boundaries with the atmosphere and solid earth. Seeks to understand sources, production, and fate of biogenic materials in the sea well enough to predict their influence on perturbations significant to the global environment. This program will be greatly enhanced by a yet-to-be-funded satellite that images ocean color.

Global Ecosystem Dynamics: Uses long-term, large-scale observations to examine the role of the terrestrial freshwater biosphere in an global earth system. Studies the structure and function of ecosystems and their interaction with the atmosphere and hydrosphere. Many of the activities of this subcomponent are organized by the NSF Directorate for Biological and Behavioral Sciences.

Ridge Crest Processes: Studies the driving mechanisms of plate tectonics, the volcanic, tectonic, and hydrothermal processes at ridge crests, and their geological, chemical, and biological effects. Research will use modern acoustic imaging systems and a long-term instrumented seafloor "laboratory."

Solid Earth Dynamics: Studies images of the earth's interior using a new global seismic network, thereby contributing to the understanding of earthquake mechanisms, convection in the earth's interior, and the dynamics of plate motion. Global Positioning Satellite (GPS) observations will contribute to our understanding of earthquake processes, plate motions, rifting, mountain building, volcanic behavior, and sea level fluctuations.

Paleoclimates from Ice Sheets: Initial focus uses cores from ice sheets that preserve and record annual precipitation and atmospheric temperature and composition, yielding hundreds of thousands of years of paleoclimatic information. This international, bipolar program will examine past climate information, ice sheet dynamics and geophysical events such as volcanic eruptions and meteor showers.

CEDAR: (Coupling, Energetics and Dynamics of Atmospheric Regions) studies the latitudinal and vertical coupling between the upper and middle atmospheric regions using optical and radio instruments in coordinated field campaigns.

In FY 1989 and beyond, NSF hopes to fund studies of climate change on both shorter and longer time scales, using all the

natural earth archives, such as tree rings, ice cores, deep sea cores, sedimentary rocks. Other research will study how marine populations grow to maturity and are distributed in the oceans. The plan also provides for studies of the interfaces between ocean and terrestrial environments. Research in the polar regions is an integral part of global geosciences.

The need for careful planning of data management and state-of-the-art modeling and networking are essential to the success of global geosciences. The science agencies have established an Ad Hoc Interagency Working Group on Data Management for Global Change, to address such issues as standardization, distribution, and accessibility of global data sets.

Global Geosciences is the product of a complex planning process that incorporates the science plans and priorities of external advisory bodies such as the boards of the National Academy of Sciences and NSF advisory committees. These disciplinary groups represent the science community, and provide NSF with long range plans for earth sciences research. NSF has integrated these plans into a comprehensive multi-disciplinary five-year plan for the Global Geosciences Program. This program remains the highest priority activity and a major focus within the NSF Geosciences Directorate.

NSF is coordinating its Global Geosciences research programs with other agencies (NASA, NOAA, USGS, DOE, and the Navy), as well as with other countries. Planning of several Global Geosciences sub-programs has proceeded at the international level by Scientific Steering Groups sponsored by the International Council of Scientific Unions (ICSU) through such committees as Scientific Committee on Oceanographic Research (SCOR), and Scientific Committee on Problems in the Environment (SCOPE); through the World Meteorological Organization (WMO), UNESCO'S Intergovernmental Oceanographic Commission (IOC), and others. For example, WOCE and TOGA are major elements of the World Climate Research Program of the WMO, and are also supported by the IOC, and SCOR (through the Committee on Climate Changes in the Ocean).

NSF is committed to long-term funding of Global Geosciences, which will continue for at least a decade. As NSF Director Bloch put it, "the National Science Foundation, together with our sister agencies, feels a responsibility and a commitment to participate in global studies of our planet. The systems approach to scientific research will not only precipitate the creation of strategic multi-disciplinary environmental datasets, but will directly invigorate the constituent earth science disciplines."

NSF enjoyed enthusiastic support from Congress and the Executive Branch throughout the FY 1987 budget cycle. We see continuing

interest in FY 1988 through Congressional requests for testimony, such as this one today, on such subjects as global change, greenhouse warming, and ozone.

Not all of the multi-disciplinary studies embodying global concerns are formally included as part of the Global Geosciences Program. NSF funds a considerable amount of research addressing global change that is part of NSF's ongoing disciplinary research programs. For example, NSF has operated an international activity in ocean drilling for more than a decade. The Ocean Drilling Program continues to produce deep sea cores from the world's oceans and margins. The sediments provide clues on such subjects as past global climates, global circulation patterns, and depositional environments.

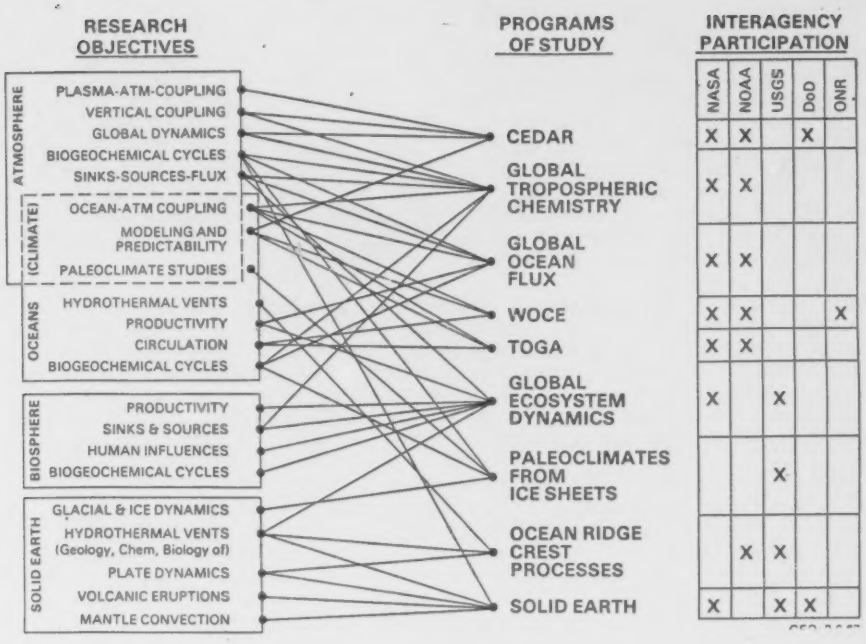
NSF also funds research on stratospheric ozone. A recent noteworthy activity was the August 1986 National Ozone Expedition (NOZE) to the Antarctic continent to study stratospheric ozone depletion. Participants were NSF, NASA, NOAA and the Chemical Manufacturers of America. NSF operates the United States Antarctic Program, and was able to facilitate a winter fly-in of scientific teams to study the "ozone hole" over Antarctica.

A third example of global change research not formally associated with Global Geosciences involves polar research programs. The polar regions are of critical importance to world climate and ocean productivity, and these inhospitable regions influence the earth's atmosphere, deep ocean circulation, and biological productivity in a profound way. NSF funds a variety of disciplinary and multi-disciplinary studies both in the Arctic and the Antarctic.

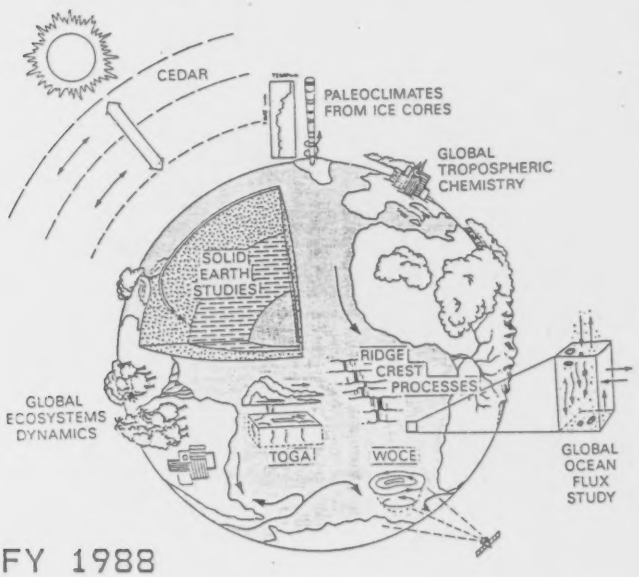
In conclusion, as we support studies of the earth system, the science agencies will continue to respond to the needs of the community. With the continued support of congress we will exploit our present resources to accommodate the various disciplinary research projects required to implement a comprehensive program to address this vital situation.

In a sense we are conducting a global experiment and the Earth is our natural laboratory. The global experiment has begun and proceeds beyond our control. We need to work quickly but thoughtfully. By continuing to work closely together, the federal agencies must serve as the collective conscience for the community, a conscience that must wrestle with how to best ensure the future habitability of planet Earth.

NSF FY 1988 GLOBAL GEOSCIENCES



GLOBAL GEOSCIENCES



FY 1988

RESPONSES TO QUESTIONS FROM SENATOR HOLLINGS

Question 1: Last year, the National Science Foundation (NSF) authorization bill contained a section requiring a report on U.S. plans for an International Year of the Greenhouse Effect.

- What is the status of that report?

Answer: Section 9 of P.L. 99-383 requires the President to inform Congress of Actions taken or proposed to be taken by the Federal Government concerning this proposal. A report entitled United States Government Activities Related to Greenhouse Effects has been drafted and forwarded to the Director, Office of Science and Technology Policy for review. This report discusses the agencies' on-going activities related to greenhouse gas phenomena.

Question 2: NSF has sometimes been identified as the most appropriate lead agency for the U.S. program.

- Do you feel that identifying a lead agency is a necessary step in development of a comprehensive U.S. Global Change Program? Why or why not?

- If lead agency identification is necessary, do you agree that NSF most appropriately fills that role?

Answer: Lead-agency roles are likely to evolve as a result of the interagency coordination process. In fact, specialization of effort among the agencies is a good way to assure that each agency has a major, visible role and is accountable for that part of the program.

NSF is the major entree to the academic community and NSF supports research in many disciplines and diverse areas of science. We work with the other agencies, assume coordination functions that become necessary, and serve as lead agency in areas where that is appropriate.

Question 3: Recently, a cooperative agreement was announced between the U.S. and the Soviet Union to study ozone and other gases that could affect the earth's climate. Around the same time, I understand that NSF withdrew an invitation for Soviet participation in the undersea Deep Earth Sampling Program, because of concerns raised by the Department of Defense.

- How would you characterize the relationship between the U.S. and the Soviet Union with respect to international research efforts?

- Do you anticipate that similar national security considerations will have to be addressed in the development of the IGBP? If so, in what areas?

Answer: While there has been a lull in U.S. - U.S.S.R. bilateral cooperation for several years, scientist-to-scientist relations between the two countries are generally good in the environmental area. The US-USSR Bilateral on Environmental Protection has been in effect for nearly 15 years.

There are no clear national security implications involved in the International Geosphere-Biosphere Programme (IGBP). If national security issues do arise, they would likely be associated with the areas of technology transfer and data exchange.

Question 4: Scientists in different fields examine the world on very different time and space scales. For example, a geologist might study regional differences developing over thousands of years in comparison to a marine biologist examining the number of microorganisms in a few drops of seawater.

- Will these differences in scale create problems in integrating data from several sources?

- What efforts are underway to resolve those problems?

Answer: Yes, differences in scales of individual processes that must be integrated to understand the whole are a problem. Meteorologists and physical oceanographers have been working on this problem for a long time and have made important progress. Their experiences and successes will have to be expanded to incorporate other disciplines, e.g., biology. The World Climate Program of the World Meteorological Organization (WMO) and the International Council of Scientific Unions (ICSU) treat this problem explicitly through the International Satellite Land-Surface Climatology Project, and plans for the International Geosphere-Biosphere Programme (IGBP) include scale interactions as a major scientific focus. ICSU's Scientific Committee on Problems of the Environment (SCOPE) has launched a study of the question of integration of processes on different scales in the biological and geophysical sciences.

Question 5: Your testimony stresses the need for long-term observation programs to address the challenge of understanding global change. By contrast, I understand most research grants awarded by NSF are for periods of 2 to 3 years.

- Given NSF's present granting system, how do you ensure continuity of the data and the kind of long-term program necessary to answer important questions regarding global trends?

Answer: The National Science Foundation generally awards grants for periods of one to three years. This enables periodic review of the state of individual scientific projects and disciplines, and allows selection and support of the best scientific proposals submitted. If the scientific progress warrants, an undertaking can be extended, or a new proposal encouraged for continuation along a related line. The long term observational programs are made up of a changing mix of individual projects. There has so far been no inherent conflict between the need for frequent review and approval and the requirement for funding that permits the making of observations over relatively long time spans.

ANSWERS TO QUESTIONS FROM SENATOR PRESSLER

Question 1: With our national budget deficit pressures increasing year-by-year, what is the urgency for initiating now a national program of "Global Change" -- why should this program assume such a high national priority? What are the likely consequences and risks if we do not initiate a Global Change program, particularly with respect to ozone depletion and the greenhouse warming effect?

Answer: Global Change is the U.S. name for a program that is being developed by the International Council of Scientific Unions (ICSU) called the International Geosphere-Biosphere Programme: A Study of Global Change (IGBP). It is a program whose time has come. First of all, we now have the technology to do what is needed. We have supercomputers to make the computations necessary to model the many and varied phenomena, and we can observe the globe using in situ and satellite techniques with the resolution needed to measure changes that occur in time. Great progress has been made in many of the sciences that have to be involved in the study of Global Change. The modeling capability in atmospheric and related geosciences is now very good; observational capabilities in oceanography, seismology, environmental chemistry, and ocean drilling have improved dramatically in the past decade; the international framework is in place; and, perhaps most important, scientists are eager and willing to spend large portions of their productive research lives investigating problems associated with Global Change.

There is a feeling in the scientific community that the global-scale environmental problems to be addressed are critically important to the nation and are tractable. These problems also have become societal issues. It is critical to initiate the research programs now so that we can responsibly address such matters as ozone depletion and the effect of greenhouse gases on global climate.

Question 2: I understand that the interagency Committee on Earth Science, chaired by NOAA Administrator Tony Calio, has begun to meet to formulate a national strategy for Global Change. What fundamental assumptions will direct this Committee's consideration of a strategy for a national Global Change program? When should this Committee complete its work, and what can we expect as the product of this Committee's work?

Answer: The Committee on Earth Sciences (CES) is just beginning to formulate its goals and terms of reference. Thus, it is difficult to predict its role in a national program of Global Change research. I hope that CES will concentrate on coordinating the U.S. program among Federal agencies, eliminating needless duplication, identifying gaps that need filling, and

integrating the various agency programs into an effective overall activity.

The CES is a standing committee of the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) and, as such, will have potential uses long after a Global Change program is initiated and well underway.

Question 3: What are the largest challenges in formulating a sensible national program and in achieving the goals and objectives of the program?

Answer: There are two major challenges. First, Global Change is a multidisciplinary problem that demands interdisciplinary research on a scale never before attempted. It requires new, or at least altered, perspectives on the part of both scientists and managers. For example, it will require creative, broadly knowledgeable scientists to deal with fundamental problems such as how to model the earth's physical, biological, and chemical processes, all acting on vastly different time and space scales, as an interactive, coupled system.

Secondly, because of its multidisciplinary and diverse nature, organizing and making available the data and information necessary to study Global Change is an absolute necessity that presents a formidable challenge.

We have recognized these basic challenges from the beginning. NSF and others have taken steps to meet them. NSF's Global Geosciences thrust, under which NSF's part of Global Change is supported, is structured as a multidisciplinary, integrated program of physical, biological, and chemical subdisciplines from various parts of the Foundation. Regarding data and information systems, NSF has joined with other agencies to assure an effective data and information effort.

Question 4: What institutional framework would allow for an effective, coordinated interagency Global Change program -- one that would optimize the potential for synergism between the involved agencies and also minimize or eliminate unnecessary duplication of effort.

Answer: The institutional framework needed to support the Global Change program is evolving. The agencies concerned are working together to assure that effective plans and strategies are in place. I expect that we will use existing federal coordinating mechanisms (e.g. the National Climate Program Policy Board), interagency coordination bodies (e.g. Interagency Working Group on Data Management for Global Change), and new mechanisms specifically established for this program (e.g. CES).

Question 5: What total federal resource commitment would be required over the next five years to support a Global Change program? Ten years? What total resource commitment from NSF would be required over the next five years to support a Global Change program? Ten years? What is an approximate five-year funding profile for NSF's role in Global Change?

Answer: NSF had $17 million for research on the changing global environment in FY 1986. In FY 1987 NSF's Global Geosciences initiative was allocated $36 million, the majority of which deals with Global Change phenomena. The NSF FY 1988 budget request contains an estimated $64 million for Global Geosciences research support on the changing global environment. (An outline of the FY 1988 Global Geosciences Program is attached). It is planned to approximately double the FY 1988 level by 1992, consistent with the overall administration budget strategy for NSF. Resource projections beyond this date are not meaningful. I cannot speak accurately concerning the total federal resource commitment as this depends on the cost allocation and program accounting procedures of other agencies.

Question 6: To what extent might we anticipate outside participation from private entities, such as laboratories, institutions, and industry in a Global Change program?

Answer: As you suggest, the private sector can play an important role in the program. Research laboratories and institutions will conduct a significant portion of the basic and applied research required. Private industry will be called upon to develop new technology and produce needed equipment and to provide long-term monitoring activities. Furthermore, industry is expected to be involved in computer technology and services.

Question 7: Concurrent with the U.S. Global Change initiative, the International Council of Scientific Unions has formulated the International Geosphere Biosphere Program (IGBP), which is also designed to conduct an interdisciplinary study of the changing global environment. How would a U.S. Global Change program be effectively coordinated with an International Geosphere Biosphere Program, and what are the challenges and likely problems in coordinating the two programs? What duplication is likely to exist in the two initiatives, and how can such duplication be minimized or eliminated?

Answer: The Global Change Program is the U.S. contribution to the International Council of Scientific Unions' International Geosphere-Biosphere Program: A Study of Global Change. Thus, it is already integrated and there should be no difficulty in

linking the U.S. program to the international one. The Chairman of the ICSU/IGBP Committee is Dr. James McCarthy, who has been central to all U.S. program planning for Global Change.

Question 8: Are there lessons that have been learned from conducting or participating in other large international science programs that might benefit the U.S. in terms of setting up an International Geosphere Biosphere Program itself and in establishing the national and international organizations?

Answer: The U.S. scientific community has learned much from past international programs. The International Geophysical Year, the International Decade of Ocean Exploration, the Global Atmospheric Research Program, and the World Climate Program are examples of large, international scientific projects that have provided the U.S. and the world with the experience necessary to set up an effective IGBP at both national and international levels. The lessons learned are: (1) Large, complex international science programs can be carried out with great success. (2) The combination of government and non-government international organizations works best, e.g., as in GARP, run by the World Meteorological Organization (WMO) and ICSU, when both are equal partners and can bring their combined resources to bear on the program. (3) Difficulties involving interdisciplinary research are generally underestimated; enlightened and broad-based leadership is required. (4) Data and information management never goes as well as expected; early and comprehensive planning is required and scientists must be involved from start to finish.

Question 9: Will the Federal agencies rely solely on the National Academy of Sciences Committee on Global Change for guidance and expert advice as to how to steer their respective contributions to the Global Change program? If not, then through what other channels?

Answer: The National Science Foundation will, in conjunction with other Federal agencies, look primarily to the new NAS/NRC Committee on Global Change for guidance with respect to the scientific planning and conduct of the Global Change program. Other NAS/NRC Committees in the atmospheric, earth, and ocean sciences will continue to provide scientific guidance with respect to Global Change research within their purviews. We also will receive scientific guidance from individual scientists through their participation in the peer review process. Further, the external Advisory Committees of NSF will provide counsel in the decision-making process with respect to the Global Change program. On the international level, we will obtain counsel and advice from ICSU and other international and intergovernmental

bodies (e.g., WMO & the Intergovernmental Oceanographic Commission).

Question 10: One of the keys to the success of a Global Change effort is the proper management of the data and the establishment of adequate information systems that have an evolutionary capability. What agency or agencies should take the lead in managing the data and in establishing the information systems?

Answer: In April of this year, senior officials from NASA, USGS, NOAA, and NSF established an Interagency Working Group on Data Management for Global Change charged with the objective of making it as easy as possible for scientists to get data appropriate to study Global Change. Activities begun this year include catalog interface standards; common data policies on acquisition, exchange, and charging; a national directory; and end-to-end tests of critical observing systems to make sure that the observations and the data management processes that we put them through yield an end product of information adequate for the study of global change. NOAA has the lead in this endeavor.

Question 11: What are the national security implications and considerations in establishing a Global Change program and in U.S. participation in an International Geosphere Biosphere Program? To what extent is the Department of Defense or any other national security agency expected to participate in a Global Change program?

Answer: The Global Change program is primarily a program of basic research. As such, national security implications should be at a minimum. Nevertheless, it must be recognized that large computer systems will be used, as will computer networks and high-tech instrumentation that could be sensitive to technology transfer policies. One of the lessons learned from international experiments is that the U.S. must remain in control of sensitive instrumentation and computers. This has been accomplished before, so there is no reason why it cannot be accomplished again. There should be no problems as long as arrangements are worked out in advance and cleared with the proper departments.

The Department of Defense is concerned about and sensitive to environmental problems, as are other agencies. There are sufficient coordinating committees and groups on which the DoD sits so that they can choose to take part or have some of their contractors take part in the various experiments and activities. In all programs of this kind, when the U.S. DoD participated, it has done so openly.

Question 12: Will U.S. plans for a Global Change program be embodied in an official statement of national policy, and how

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will a determination be made as to whether sufficient budgetary support has been committed to the program?

Answer: There are numerous Executive Branch policy statements establishing this research as an area of national importance, including the President's 1987 State of the Union Address. Principal expressions are the budget justifications of Federal agencies -- NASA, NOAA, NSF, and others -- and annual testimony in support of these budget requests. Others are statutory in origin, such as the amendments to the Clean Air Act of 1977, that led to the National Plan for Stratospheric Ozone Monitoring and Early Detection of Change--1981-1986. There are other expressions on specific aspects, as for example the objectives of the National Climate Program Act, Public Law 95-367, and amendments, Public Law 99-272.

The Global Change program is a long-term research enterprise that, as it accumulates knowledge, will be identifying additional questions and areas of emphasis. Government-wide planning for the Global Change program needs several budget planning cycles and interagency reviews prior to any formal policy governing a specific approach and overall funding level. This flexibility will allow the various agencies, in cooperation with the science community, to identify a realistic and responsible Global Change program, especially in the current constrained fiscal environment. The knowledge gained from this initial planning process will eventually permit the development of a scientifically sound and fiscally realistic national policy. Relative to other research areas of national significance, it appears that Global Change program resources, for the most part, are commensurate with agency needs over the current planning period.

Question 13: By what standards should a U.S. Global Change program be measured, and what should be the measure of "success" in this program? For what scientific reasons might it be necessary to discontinue a Global Change program after it is initiated, or, put another way, is there a quantitative or qualitative threshold that such a program should meet in order to justify its continuation?

Answer: The measurement of progress is perhaps best viewed as operating on three levels. The first is that of the individual research project and is governed by the merit review system. That is, the research ideas proposed are evaluated by relevant competent scientific authority. Progress measurement occurs whenrenewed support is requested. Prior project progress is an explicit consideration for continuation of support.

The second level entails periodic coherent area review. NSF Advisory Committees are required to carry out such analysis at

least every three years. In addition, NAS ad hoc panels have been and will continue to be established to assess accomplishments in broad areas. This type of review not only measures progress against key research objectives, but it is also of great importance in getting better articulation of the science questions that remain.

The third level is the evaluation of operationally descriptive and predictive models. The matter of describing and making useful predictions of regional responses to Global Change is the payoff. This is an extraordinarily ambitious science objective that will require on the order of a decade or more of sustained effort before tests and demonstrations of this nature will be in hand. Constant monitoring by the Academy of Sciences, agency advisory committees, agency budget and program reviews, OMB, GAO, and other national entities will assure the program meets objectives and produces results critical to the nation.

Question 14: It is widely understood that satellite land remote sensing will play an important role in a Global Change program. Just how critical will satellite land remote sensing data be to the success of such a program? How important is a U.S. satellite land remote sensing capability to a Global Change program, and to what extent would a U.S. commercial land remote sensing capability be able to meet these national requirements? To what extent should the U.S. be expected to rely on satellite land remote sensing data from foreign satellite systems -- would this be a practical option if there were no U.S. Landsat system?

Answer: NASA, NOAA, and DOD are the agencies most directly involved with satellites and their operation. NSF's interest is to ensure that our investigators receive satellite data at a reasonable cost and that the access to the data is uncomplicated. There is no question that satellite remote sensing will be important to the Global Change program.

Question 15: Similarly, how important would the capabilities offered by EROS Data Center be to a Global Change program, and how might the functions of this facility be expanded to support a Global Change program?

Answer: Again, NSF is not directly involved in the operation of satellites. Our overriding interest is in assuring that satellite data are easily accessible to scientists at a reasonable cost.

Question 16: Is the U.S. scientific academic infrastructure of high schools and colleges sufficient to support such a national Global Change initiative, not only with research but also with a

steady supply of qualified scientists? If not, what is being done to address this deficiency? Do human resource problems exist on an international scale?

Answer: While the academic infrastructure is capable of supporting this effort, future improvements may be needed. NSF has initiated, Foundation-wide, corrective measures. The Global Change program is an extraordinarily exciting program that we believe will attract students at all educational levels.

The educational infrastructure is adjusting and NSF itself has begun selective educational support activities. Universities have begun to organize so as to focus on the geosciences as a coherent area. Undergraduate programs at large research universities can be expected to change in this direction.

Expansion of undergraduate programs generally -- in the form of instrumentation, student, and faculty support -- will facilitate development of stronger programs. The NSF Geosciences Directorate, in addition, is applying substantial funding (on the order of $10-15 million annually) in various efforts to improve the quality of geoscience-related educational experiences. One successful undertaking is the Research Experience for Undergraduates (REU) program, which appears to be effective in bridging the gap between undergraduate programs and the primarily graduate-based geosciences.

Other nations, especially the smaller ones, have similar problems in the science cadre structure.

Question 17: What, if any, technologies need to be developed to adequately address the issues that are central to Global Change, and what level of federal investment would be required to develop these technologies? Similarly, how great an investment in national facilities must be made to support a Global Change initiative?

Answer: Most of the technologies required for Global Change research exist or their development is underway (satellites, data systems, supercomputers, and advanced instruments). In some instances, new technologies, developed by industry for other purposes, e.g., information systems or biotechnological tools for ocean research, can be adapted for Global Change.

Existing and planned national facilities and instrumentation will play a crucial role in Global Change research. In the NSF/GEO long-range plan 1989-1993 we have identified new facilities and instrumentation, costing $500M over the five years, that will serve our core programs including Global Geosciences/Global Change. These include:

a) global networks of geophysical observatories
b) oceanic including polar vessels
c) a post-XMP supercomputer
d) accelerator mass spectrometry facilities for earth and ocean applications
e) ice and ocean-bottom drilling capability upgrades
f) marine laboratory upgrades
g) upgraded research aircraft capabilities

Senator GORE. Thank you very much.

Our next witness is Dr. Lennard Fisk who is Associate Administrator of NASA and for Space Science and Applications. And we welcome you, Dr. Fisk. If you want to summarize portions of your testimony, we would appreciate it.

STATEMENT OF DR. LENNARD A. FISK, OFFICE OF SPACE SCIENCE AND APPLICATIONS, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Dr. FISK. Senator, thank you very much. I am pleased to be here today to discuss NASA's involvement with other Federal agencies in developing a national global change program, as well as our potential role in international efforts.

It is evident, as other speakers have mentioned, that the earth is a planet characterized by change, and we have now entered an era in which the human race has achieved the ability to alter the environment on a global scale.

We have had extensive discussions today on two problems, ozone and global greenhouse warming, which are presently at the attention of many scientists and policymakers. But these are, of course, just two of interrelated environmental issues that we face.

As other speakers have mentioned, to gain a scientific understanding of the activities that will affect the earth environment requires a whole new approach to earth science.

We at NASA, as do the other agencies, subscribe to the view that what is needed is an understanding of the entire earth as a system, on a global scale, including a description of how its component parts and their interactions have evolved, how they function, and how they are expected to change on all time scales. And of course the immediate challenge is to develop the ability to predict how those changes will occur over the next decade to century, both in response to natural stimuli, and also in response to human activities.

Now some specific areas where NASA is currently focusing its efforts, and which demonstrate our commitment to understanding global change phenomena include the following.

We have played a major role in understanding stratospheric ozone layer. NASA is a strong supporter of research in this area and regularly prepares both for Congress and the EPA assessments of the state of knowledge of the ozone.

Dr. Corell mentioned a moment ago the issue of ozone depletion in the Antarctic. There is a major campaign underway that will begin this August, jointly between NASA, NOAA, NSF and the Chemical Manufacturing Association to continue research in that area.

The campaign consists of two components. A ground-based campaign, which is coordinated by the NSF at McMurdo, and an aircraft campaign organized and managed by NASA, on behalf of the four agencies.

The campaign will also use real-time satellite data. The aircraft campaign has been afforded the highest priority within our Earth Science and Applications Division at NASA and the NASA Ames Research Center, where the aircraft are maintained and operated.

The increasing concentration of methane, which both Dr. Press and Dr. Moore mentioned, is another area that is receiving significant attention in NASA. Just two years ago we began an interdisciplinary research program, one focus of which is to achieve an understanding of the cause of the methane increase.

Back in 1982, with the view that the earth needs to be studied as an integrated system, NASA took the lead and initiated a series of workshops to define the scope of such a research program.

In 1983, the Advisory Council for NASA established the Earth Systems Study Committee, which has been mentioned earlier, and provided NASA, NOAA, and the NSF with a clear definition of their specific roles in earth science.

The goals of this research program are totally consistent with those proposed by the National Academy of Science and the ICSU Global Change Program. The Academy has also reviewed the NASA program and is strongly supportive of it.

The NASA implementation plan is based on continuing support for basic research and analysis, as well as the completion of approved satellite programs. The upper atmospheric research satellite, or UARS, which will provide the first global integrated ozone measurements, is scheduled to be launched in 1991.

The ocean topography experiment, providing global measurements of ocean circulation, the NASA scatterometer, which is to fly on the Navy remote ocean sensing system, or NROSS, provides wind-ocean interaction studies.

And finally the implementation of the planned earth observing system, or EOS, which will use the polar platform which is being developed as part of the space station. EOS was recognized by the Earth Systems Study Committee as a centerpiece of NASA's activities, with respect to global change.

Space, of course, offers a unique perspective of the earth. If you want to understand the global earth, you have got to do remote sensing from space.

By capitalizing on the increases in spacecraft size, capabilities, increased improvements in remote sensing instrumentation, advances in data system, EOS will be able to measure many of the parameters of the earth system in new ways, which are consistent with the time scales and space scales that are needed to understand the earth as a system.

EOS will also provide sustained capability over many years, which will provide an opportunity to see long-term trends in the data, some of which are quite subtle and which need to be measured over long times in order to understand.

The comprehensive and coordinated national-international effort is clearly required to do the study of the earth as a system, and NASA is prepared to do all it can to fulfill its mission in this area.

Thank you.

[The statement and questions and answers follow:]

STATEMENT OF

DR. LENNARD A. FISK

OFFICE OF SPACE SCIENCE AND APPLICATIONS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

BEFORE THE

SUBCOMMITTEE ON SCIENCE, TECHNOLOGY AND SPACE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

SENATE

Mr. Chairman and Members of the Subcommittee:

I am pleased to be here today to discuss NASA's involvement with other federal agencies in developing a national Global Change program, as well as NASA's potential role in international efforts.

It is evident that the Earth is a planet characterized by change. We have entered an era in which the human race may have achieved the ability to alter its environment on a global scale. The ozone and global greenhouse warming issues which are presently at the center of attention of many scientists and policymakers are just two of the interrelated environmental issues we face today.

To gain a scientific understanding of how human activities will affect the Earth's environment requires a new approach to Earth sciences. We need to obtain a scientific understanding of the entire Earth system on a global scale by describing how its component parts and their interactions have evolved, how they function, and how they may be expected to continue to change on all time scales. In particular the immediate challenge is to develop the capability to predict those changes that will occur in the next decade to century, both naturally and in response to human activity. This will require a nationally and internationally coordinated program of interdisciplinary research to investigate long-term, 10-100 years, coupled physical, chemical, and biological changes in the Earth's environment recognizing that land, atmospheric, oceanic, and biospheric processes are strongly coupled on a variety of temporal and spatial scales.

I will first describe for you briefly the current scientific understanding of the ozone and global warming issues which are just two examples of the type of potential environmental changes relevant to a Global Change program.I will then proceed to describe in detail the current NASA atmospheric chemistry and climate research programs which are improving our current understanding of the ozone and global climate system. These programs which combine basic Research and Analysis programs along with satellite prc grams will form the basis of NASA's role in any future national and international Global Change program.

SCIENTIFIC REVIEW:

While I will describe the ozone and climate programs separately, it is now recognized that the ozone and greenhouse warming issues are strongly coupled because changes in ozone are predicted to modify the Earth's climate, and because the same gases which are predicted to modify ozone are also predicted to produce a climate warming.

For several decades scientists have sought to understand the complex interplay among the chemical, radiative, and dynamical processes that govern the structure of the Earth's atmosphere. During the last decade or so there has been particular interest in studying the processes which control atmospheric ozone since it has been predicted that human activities might cause harmful effects to the environment by modifying the total column amount and vertical distribution of atmospheric ozone. Ozone is the only gas in the atmosphere that prevents harmful solar ultraviolet radiation from reaching the surface of the Earth. Unlike some other more localized environmental issues, e.g. acid deposition, ozone layer modification, like global greenhouse warming, is a global phenomenon which affects the well-being of every country in the world. Changes in the total column amount of atmospheric ozone would modify the amount of biologically harmful ultraviolet radiation penetrating to the Earth's surface with potential adverse effects on human health (skin cancer and suppression of the immune response system) and on aquatic and terrestrial ecosystems. Changes in the vertical distribution of atmospheric ozone, along with changes in the atmospheric concentrations of other infrared active (greenhouse) gases, could contribute to a change in climate on a regional and global scale by modifying the atmospheric temperature structure which could lead to changes in atmospheric circulation and precipitation patterns. The so-called greenhouse gases are gases which can absorb infrared radiation emitted by the Earth's surface, thus reducing the amount of energy emitted to space, resulting in a warming of the Earth's lower atmosphere and surface.

The ozone issue and the greenhouse warming issue are strongly coupled because ozone itself is a greenhouse gas, and because the same gases which are predicted to modify ozone are also predicted to produce a climate warming. These gases include carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), several chlorofluorocarbons (CFC's), including chlorofluorocarbons 11 ($CFCl_3$) and 12 (CF_2Cl_2), and Halons 1211 (CF_2ClBr) and 1301 (CF_3Br). CH_4, N_2O, the CFC's, and the Halons, respectively, are precursors to the hydrogen, nitrogen, chlorine oxides, and bromine oxides which can catalyze the destruction of ozone in the stratosphere by a series of chemical reactions. Concentrations of these gases in the parts per billion range control the abundance of ozone whose concentration is in the parts per million range, e.g. one molecule of a chlorofluorocarbon destroys thousands of molecules of ozone. CO and CO_2 can affect ozone indirectly. CO controls the concentration of the hydroxyl radical in the troposphere which itself controls the atmospheric concentrations of some of the gases which can affect stratospheric chemistry. CO_2 plays a key role in controlling the temperature structure of the stratosphere which itself is important in controlling the rates at which the hydrogen, nitrogen, and chlorine oxides destroy ozone.

There is now compelling observational evidence that the chemical composition of the atmosphere is changing at a rapid rate on a global scale. The atmospheric concentrations of CO_2, CH_4, N_2O, and CFC's 11 and 12 are currently increasing at rates ranging from 0.2 to 5.0% per year. The concentrations of other gases, including CFC 113 and Halons 1211 and 1301, important in the ozone and global warming issues are also increasing, some at an even faster rate. These changes in atmospheric composition reflect in part the metabolism of the biosphere and in part a broad range of human activities, including agricultural and combustion practices. It should be noted that the only known source of the CFC's and Halons is industrial production. They are used for a variety of uses, including aerosol propellants, refrigerants, foam blowing agents, solvents, and fire retardants. At present one of our greatest difficulties in accurately predicting future changes in ozone or global warming is our inability to predict the future evolution of the atmospheric concentrations of these gases. We need to understand the role of the biosphere in regulating the emissions of gases such as CH_4, CO_2, N_2O, and methyl chloride (CH_3Cl) to the atmosphere, and we need to know the most probable future industrial

release rates of gases such as the CFC's, Halons, N2O, CO, and CO2 which depend upon economic, social, and political factors.

One important aspect of the ozone and global warming issues is that the atmospheric lifetimes of gases such as N2O, CFCl3, and CF2Cl2 are known to be very long. Consequently, if there is a change in atmospheric ozone or climate caused by increasing atmospheric concentrations of these gases the full recovery of the system will take several tens to hundreds of years after the emission of these gases into the atmosphere is terminated.

Numerical models are used as a tool to predict to what extent human activities will modify atmospheric ozone and climate. One-dimensional models are used to predict changes in the column content of ozone and the vertical distribution of ozone and temperature, but cannot predict variations in ozone or temperature modification with latitude, longitude, or season. Major progress has been made over the past few years to develop two-dimensional models which can predict the variation of ozone and temperature change as a function of season and latitude. Three-dimensional models which include longitudinal variations are being developed to study the coupling between the chemical, radiative, and dynamical processes which control the distribution of ozone and temperature, but these models are not yet ready to perform perturbation calculations.

Because it is now well recognized that the chemical effects of these gases on atmospheric ozone are strongly coupled and should not be considered in isolation, the most realistic calculations of ozone change take into account the impact of simultaneous changes in the atmospheric concentrations of CO2, CH4, N2O, the CFC's, and possibly other gases such as CO, oxides of nitrogen (NOx), and bromine containing substances. The effects of these trace gases on ozone are not simply additive. Increased atmospheric concentrations of CFC's and N2O are predicted to decrease the column content of ozone, whereas, increased atmospheric concentrations of CO2 and CH4 are predicted to increase the column content of ozone. Therefore, it can be seen that the effects of increasing concentrations of CFC's and N2O are to some degree offset by increasing concentrations of CO2 and CH4 as shown in figure 1. This is contrasted to the global warming issue where increased atmospheric concentrations of the same trace gases are all predicted to increase the temperature of the atmosphere in an approximately cumulative manner.

One-dimensional model calculations have been performed to predict how ozone would change with time assuming that the atmospheric concentrations of CO2, CH4, and N2O continue to increase at their current rates of 0.5, 1.0, and 0.2% per year, respectively, for the next 100 years, in conjunction with different assumptions for the annual growth rates in the emission of chlorine and bromine containing chemicals. Continued growth of CFC's and Halons at 3% per year, which is consistent with economic projections, is predicted to yield a globally averaged over head column ozone depletion of about 6% by the year 2040 and more thereafter, which is greater than natural variability and hence significant (not shown in figure 2). In contrast, a true global freeze of the sum of world-wide emissions of all chlorine and bromine containing chemicals at or below projected 1990 levels is calculated to result in global column ozone depletions of less than one percent by the year 2015 and less thereafter (figure 2). The results of these calculations demonstrate the strong chemical coupling that exists between these gases, and the time scale on which ozone changes are predicted to occur. In essence, when the growth rates of the CFC's are less than the growth rates of CH4 and CO2 only small column ozone changes are predicted because the CFC effects on ozone are temporarily masked. However, when the growth rates of the CFC's exceed those of CH4 and CO2, these gases can no longer buffer the impact of the CFC's and large ozone depletions are predicted. Figure 2 also shows the impact of non-compliers to an international CFC-protocol.

It should be noted that even when the predicted column ozone changes are small, as in the case of a true global freeze, and hence little change is expected in the amount of ultraviolet radiation reaching the Earth's surface, major changes in the vertical distribution of ozone are still predicted with potential consequences for climate. Figure 3 shows that ozone is predicted to decrease in the middle to upper stratosphere due primarily to the increasing concentrations of CFC's, and to increase in the troposphere due primarily to the increasing concentrations of CH4. The large predicted reductions in ozone near 40 km will lead to a local cooling of about 5 degrees centigrade. The consequences of this cooling to climate at the Earth's surface are currently unclear.

Two-dimensional models predict a significant variation in the ozone column decrease with latitude with the greatest depletions occurring at high latitudes. Depending upon the exact trace gas scenario used to predict ozone change, the pole to equator ratio of ozone depletion can range from a factor of 2 to 10. Seasonal effects are predicted but are somewhat less pronounced than the latitudinal effects. In general, two-dimensional models predict somewhat greater amounts of ozone depletion for the same trace gas scenarios than do one dimensional models. For example, one two-dimensional model calculation for a true global freeze predicts a global average ozone depletion of about two percent during the next 50-70 years with a depletion of 1% at the equator, 2.5% at 30 degrees North, and up to 8% at 60 degrees North (figure 4). This particular model predicts somewhat larger latitudinal gradients than other models and did not take into account the partially offsetting impact of future changes in CO2 which would lower these depletion estimates by about 25%.

A crucial question is to assess the extent of changes in global ozone that have already taken place, and to compare the changes to what has been predicted by theory. The search for global ozone trends involves looking for small secular changes amidst large natural variations that occur on many time scales. Observations of the total column content and the vertical distribution of ozone have been made for several decades using networks of different measurement techniques. Unfortunately, each of these observational techniques have certain limitations which tends to restrict our confidence in the results. These limitations arise from factors such as the lack of continuity of reliable calibration and the uneven geographic distribution of stations. Statistical analyses of the data are required to identify small trends, amongst high natural variability, using data from relatively few stations.

Ground-based observations show that column ozone generally increased about 3% from 1960 to the early 1970's, remained constant throughout the 1970's, and has decreased thereafter by about 4% (figure 5). In general, analyses for the trends in the total global column content of ozone using data from the ground based Dobson spectrophotometer network show no statistically significant trend since 1970, in agreement with model predictions for the same period when the changes in all of the trace gases are taken into account. It can also be seen from figure 5 that the values of total global column ozone since 1982 have exhibited significant variability following the eruption of El-Chichon and the largest El-Nino event of this century.

Trend estimates have also been made for the altitude profile of ozone from the network of stations using the Umkehr technique. Deriving an accurate trend for changes in the vertical distribution of ozone is more difficult than for the total column because there are fewer stations and the Umkehr measurements are very sensitive to the presence of aerosols in the atmosphere. Recent volcanic eruptions such as El-Chichon have deposited large quantities of aerosols into the stratosphere and thus the Umkehr data must be corrected. After correcting the derived ozone amounts fo. the aerosol interference, an estimate of the ozone

trend in the middle and upper stratosphere (30 to 40 km) gives a 2 to 3% decrease for the period 1970 to 1980. The magnitude of the change is broadly consistent with the predictions of photochemical models which predict that chlorine will have its maximum effect at this altitude (figure 6).

A recent unpublished analysis of Nimbus 7 satellite Solar Backscatter Ultraviolet (SBUV) data has indicated that there has been a statistically significant change in both the total column content (a decrease) and the vertical distribution (a decrease in the middle and upper stratosphere) of atmospheric ozone between 1978 and 1984. Further analysis of the data indicates that most of the change has occurred since 1981. NASA and the rest of the scientific community believe that it imperative that all ground-based and satellite ozone data be reanalyzed and interpreted as soon as possible. It is crucial to evaluate whether the data has been analyzed correctly, and if so, whether the decrease is due to natural causes such as a decrease in solar radiation, the 1982 eruption of El-Chichon, or the 1982 El-Nino event, or whether it is due to human activities such as the use of chlorofluorocarbons.

Therefore, during the fall of 1986 NASA in conjunction with the Federal Aviation Administration (FAA), the National Oceanic and Atmospheric Administration (NOAA), the World Meteorological Organization (WMO), and the United Nations Environmental Program (UNEP) launched a major review of all ozone data. An ozone trends panel composed of eminent scientists from federal agencies, research institutions, private industry, and universities was selected in early November and first met in mid-December 1986. The report will focus on trends in ozone, both total column and vertical profile. Full understanding will require parallel consideration of tends in other important parameters: temperature, solar flux, nitrogen oxides, chlorine oxides, etc.

Four subgroups were established in December 1986 and have made significant progress to date. These subgroups are studying: (a) Calibration Procedures and Instrument Performance; (b) Information Content of Algorithms; (c) Satellite-Satellite Data Intercomparisons; (d) Satellite-Ground-Based Data Intercomparisons. An additional seven subgroups were established in March 1987 and have only just started their work: (e) Comparison of Observed and Theoretically Predicted Trends; (f) Trends of Other Chemical Constituents in the Stratosphere; (g) Statistical Procedures used to Analyze Trend Data; (h) Trends in Source Gases, e.g. CO_2, CH_4, N_2O, and CFC's; (i) Aerosol Abundances and Distributions; (j) Trends in Stratospheric Temperatures; and k) Observations and Theories Related to the Antarctic Ozone Hole.

Important new observational evidence on ozone changes has recently been obtained. Data from a single Dobson instrument at Halley Bay (76 S, 27 W) has indicated a considerable decrease (greater than 40%) in the total column content of ozone above the Antarctic during the spring period (late August to early November) since 1957 with most of the decrease occurring since the mid 1970's. Satellite measurements using both the Nimbus 7 Total Ozone Monitoring System (TOMS) and the SBUV instruments have verified this trend over the Antarctic since 1979 and have demonstrated the spatial and temporal variations in this feature. It can be seen from the satellite data that the ozone decreases are not just confined to an area above Antarctica but extend from the South Pole to about 55 degrees South. Figure 7 shows the decrease in the monthly mean concentrations of the column amount of ozone over the Antarctic in October observed from 1979 to 1986. It should be noted that the amount of ozone in 1986 during October was higher than that observed in 1985. This may simply be the result of known interannual variability in atmospheric ozone or the start of a recovery in Antarctic ozone. During September the concentrations of ozone in 1986 were comparable to those in 1985. Ozone changes of a comparable magnitude are not observed over the Arctic. It is not yet evident whether the behavior of ozone above the Antarctic is an early warning of future changes in global ozone or whether

it will always be confined to the Antarctic because of the special geophysical conditions that exist there. Both chemical and dynamical explanations have been advanced to explain the observation. While it has been suggested that these Antarctic ozone decreases are caused by increasing concentrations of chlorine in the stratosphere, no credible mechanism has been demonstrated. It is clear that the models using present chemical schemes are unable to simulate this effect. Until the processes responsible for the decrease in springtime Antarctic ozone are understood, it will not be possible to state with any certainty whether it is a precursor of a global trend.

A major ground-based field measurement campaign took place at McMurdo between August and November of last year to study the ozone layer above the Antarctic. This campaign was cosponsored and coordinated by NASA, the National Science Foundation, the National Oceanic and Atmospheric Administration, and the Chemical Manufacturers Association. The campaign was exceedingly successful and the data from all four groups of experimentalists has now been analyzed. An extensive set of measurements of the chemical composition was obtained which will provide an important test of the different theoretical explanations of the Antarctic ozone hole. The measurements include hydrochloric acid, chlorine nitrate, chlorine monoxide radical, chlorine dioxide, nitric acid, nitrogen dioxide, nitric oxide, nitrous oxide, hydrofluoric acid, ozone and other chemical species. It is clear that the chemical composition of the lower stratosphere over Antarctica is significantly perturbed relative to that expected from theoretical considerations using standard homogeneous chemistry. The abundances of odd nitrogen species are low, while the abundances of odd chlorine species are high. However, in my opinion it is premature to conclude that the cause of the loss of ozone over Antarctica is due to chlorofluorocarbons. Consequently, while this campaign was a major success with excellent data on the chemical composition of the springtime Antarctic atmosphere, it is clear that additional scientific data is required for further refinement of our understanding of the processes controlling ozone in and around Antarctica. Therefore NASA, NOAA, NSF, and the CMA are mounting a major campaign using ground-based, aircraft, and satellite instrumentation during the Antarctic springtime, from mid-August onwards, in 1987. This consists of two components: (a) the 1987 ground-based campaign, coordinated by NSF at McMurdo which will be somewhat expanded in scope compared to the 1986 NOZE I campaign; and (b) A 1987 aircraft campaign, organized and managed by NASA on behalf of the four agencies, using the NASA ER-2 and DC-8 aircraft as platforms for instruments operated by scientists from NASA Centers, the NOAA Aeronomy Laboratory, the National Center for Atmospheric Research, universities and private industry. This campaign will also utilize real-time satellite data. This aircraft campaign has been afforded the highest possible priority within the Earth Science and Applications Division at NASA Headquarters and at the NASA Ames Research Center in California where the aircraft are maintained and operated.

The scientific payloads for both the ER-2 and the DC-8 have been selected to critically test the proposed CFC, solar, and dynamical theories proposed to date. In addition, the scientific payload has also been scoped in order to obtain a broad base of scientific data in case all currently proposed mechanisms are incorrect. The campaign, which will involve over 100 scientists, engineers and pilots will be based in Punta Arenas, Chile, and is planned to begin mid-August and continue until the beginning of October.

A key question still remains concerning the reliability of the models used to predict ozone change. Given that we cannot directly test the accuracy of a prediction of the future state of the atmosphere, including the distribution of atmospheric ozone, we must test the models by trying to simulate the present atmosphere, including the distribution of atmospheric ozone, or by trying to simulate the evolution of the atmosphere, in particular ozone, over

the past few years. This is done by comparing model predictions with atmospheric observations.

We should note that nearly all the key chemical constituents that are predicted to be present in the atmosphere, and that are important in ozone photochemistry, have now been observed. In general, the models predict the distribution of the chemical constituents quite well. However, the measurements are not adequate for critically testing the reliability of the photochemical models. Close examination of the intercomparison of measurements and model simulations of the present atmosphere reveal several disturbing disagreements. One of the major disagreements appears to be that modeled ozone concentrations are typically 30 to 50% lower than measured ozone concentrations in the upper stratosphere where it should be easiest to predict the concentration of ozone, and where chlorine is predicted to have its maximum effect. These types of disagreements limit our confidence in the predictive capability of these models. In the end, however, our predictive capability will be tested by measuring the changes taking place in the atmosphere. This will require careful measurements of critical species to be carried out over long time periods, i.e. decades. NASA, NOAA, and CMA recently cosponsored a workshop to design a "Network for the Detection of Stratospheric Change." This network would be designed primarily to provide the earliest possible detection of changes in the chemical and physical structure of the stratosphere, and the means to understand them. Implementation of such a network is a high priority.

As stated earlier, the observed increases in the atmospheric concentrations of the CFC's, CH4, CO2, and N2O also have direct implications for the Earth's radiative balance through the so-called greenhouse effect. These gases absorb infrared radiation in a part of the spectrum which is otherwise transparent. Presently, and in the near future, changes in the concentrations of trace gases other than CO2 are thought to be contributing to the greenhouse warming of the Earth's surface and lower atmosphere by an amount that is about equal to that due to changes in the concentration of CO2 (figure 8). The cumulative effect of the increase in all trace gases for the period 1850 to 1980 is a predicted equilibrium warming (this neglects the heat capacity of the oceans) in the range 0.7 to 2.0 K, about half of which should have occurred to date. Model calculations indicate that the greenhouse warming predicted to occur during the next 50 years should be about twice that which has occurred during the previous 130 years. Thus, problems of ozone change and climate change should be considered together. It is also apparent that what has been previously thought of as the CO2-climate problem should more properly be thought of as the trace gas-chemistry-climate problem. The key issues are the magnitude and timing of the predicted global warming. The magnitude is not only sensitive to the rate of change of the atmospheric abundances of the trace gases, but also depends upon future changes in cloud cover and distribution. The timing of the warming is largely controlled by the rate at which the oceans and atmosphere equilibrate.

It is clear that significant progress has been made in our understanding of the physical and chemical processes that control the distribution of ozone and the temperature structure of the atmosphere. However, we must recognize that significant uncertainties in our knowledge remain, and that these can only be resolved by a vigorous program of research.

PLANNING AND AGENCY ROLES FOR THE GLOBAL CHANGE PROGRAM:

In 1982 NASA and the scientific community recognized that in order to study the processes which lead to physical, chemical, and biological changes of the Earth on a global scale, it is necessary to study the Earth as an integrated system, because the land, the atmosphere, the oceans, and the biosphere are coupled on the time scales of a decade or longer. With this

view in mind NASA took the lead and initiated a series of workshops to define the scope of such a research program called "Global Habitability" of which the goal is to investigate long-term coupled physical, chemical, and biological changes in the Earth's environment on a global scale.

One of the eight NASA Agency "GOALS and OBJECTIVES" is to "Conduct an effective and productive Space and Earth Sciences Program which expands human knowledge of the Earth, its environment, the solar system, and the universe" with a goal to establish, in cooperation with the scientific community, other federal agencies, and international organizations, an active long-term Earth Sciences Program.

To accomplish this goal requires a comprehensive Earth Science Research Program involving space-based, suborbital, land-based, and sea-based measurements; laboratory, theoretical, and instrument and model development studies, with national and international cooperation and participation.

The Earth System Sciences Committee (ESSC), which was established in 1983 by the Advisory Council of NASA, has provided NASA , NOAA, and the NSF with a clear definition of their specific roles in Earth System Science. The goals and objectives of the research program formulated by the ESSC are totally consistent with the proposed NAS and ICSU Global Change programs. The NAS reviewed the intellectual content of the NASA Global Habitability program, which is a major component of the program recommended by the ESSC, its relevance and importance to the World Climate Program, the World Ocean Climate Experiment, and other national and international programs, both ongoing and planned, including the Global Change program. The report strongly endorsed the NASA program.

The National Academy of Sciences/National Research Council (NAS/NRC) and the International Council of Scientific Unions (ICSU) are currently formulating a research program known as the Global Change or the International Geosphere Biosphere Program (IGBP). This program would build upon the many excellent ongoing national and international research programs in Earth sciences and would not duplicate or replace them.

NASA is ready to cooperate fully in the detailed scientific planning of such a program in conjunction with the scientific community through the NAS/NRC and ICSU, and implementing the U.S. component of this program with the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), the Department of Energy (DOE), and other government agencies.

The NASA implementation plan is based on continued strong support for the Research and Analysis programs described below, expansion of the concept of the interdisciplinary research program, completion of approved satellite programs including the Upper Atmospheric Research Satellite (UARS), the Ocean Topography Experiment (TOPEX), the NASA Scatterometer (NSCAT) planned to fly on the Navy Remote Ocean Sensing System (N-ROSS), and implementation of the planned Earth Observing System (Eos) which will make use of the polar platforms being developed as part of the international Space Station effort.

Any future interdisciplinary, integrated Earth Science program, will require an interactive Global Resource Information System. NASA has initiated a number of pilot programs to establish the requirements for such a system. Specifically, the two critical issues being addressed are:
(1) how best to create a data management system capable of dealing with interdisciplinary and multidisciplinary questions of global scope, and

(2) how best to provide, in advance, for handling the unprecedented flow of digital information that will be generated by the polar orbiting space platforms planned for Eos. Additionally, NASA and the United Nations Environment Program (UNEP), working with the Department of State, have established a Global Resource Information Database system (GRID).

Of course, NASA understands the fiscal realities that confront us, and will continue to evaluate our Earth System Science efforts, like the unapproved Eos, in the context of the rest of our space program.

CURRENT NASA RESEARCH PROGRAMS RELATED TO GLOBAL CHANGE:

(1) ATMOSPHERIC CHEMISTRY

A. THE UPPER ATMOSPHERIC RESEARCH PROGRAM

The long-term objectives of the NASA Upper Atmosphere Research Program are to perform research to:

(1) understand the chemical, dynamical, and radiative processes that control the physical structure and chemical composition of the Earth's upper atmosphere, and

(2) accurately assess possible perturbations of the upper atmosphere caused by human activities.

Specifically, of greatest urgency at present is an assessment of the combined effects of continued increases in the atmospheric concentrations of carbon monoxide (CO), carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), oxides of nitrogen (NOx), and halogen containing gases such as chlorofluorocarbons 11, 12, 113 and methylchloroform (CH3CCl3), Halons 1211 and 1301 on atmospheric ozone and the climate system. Our knowledge of the key physical and chemical processes controlling the chemical composition and structure of the upper atmosphere has advanced significantly during the last few years. However, we must recognize that significant uncertainties in our knowledge still remain and can only be resolved by a vigorous program of research. NASA is committed to continuing its leadership role in studying the upper atmosphere and working closely with the university and non-university scientific community; other U.S. government agencies, in particular the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), the Environmental Protection Agency (EPA), and the Federal Aviation Administration (FAA); industry, i.e. the Chemical Manufacturers Association (CMA); and other national and international scientific agencies, e.g. the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP), to resolve these outstanding uncertainties in an expeditious manner.

NASA's program is broad and comprehensive and its research activities generally fall into three general categories:

(1) Field Measurements and Technology Development:
This activity consists of studying the geographic distributions and strengths of trace gases released at the Earth's surface, measuring the solar irradiance incident on the Earth's atmosphere, determining the chemical composition and physical structure of the atmosphere using a balanced set of in-situ and remote sensing techniques, and the development of instrumentation. A wide range of instruments are currently being utilized on a variety of platforms including aircraft, balloons, rockets, space shuttle, and satellites. Ground based observations are also performed. The principal objective of the field measurements

program is to provide a description of the composition and structure of the atmosphere which can be used as a test of the theoretical models. These field and satellite programs will overcome our greatest shortcoming which is that we are presently data limited. The most important recent development in our knowledge of the chemical composition and structure of the stratosphere has been the analysis validation and release of data obtained by instruments flown on the Nimbus 7 (the Limb Infrared Monitor of the Stratosphere (LIMS), the Stratospheric and Mesospheric Sounder (SAMS), and the Solar Backscatter Ultraviolet/Total Ozone Monitoring System (SBUV/TOMS)), Applications Explorer II (AEM-2) (the Stratospheric Aerosol and Gas Experiment (SAGE), and Solar Mesospheric Explorer (SME) (visible and infrared spectrometers) satellites, and on the Space shuttle (the high resolution ATMOS infrared interferometer). This data is currently undergoing further intensive interpretation.

(2) Laboratory Studies:
Laboratory measurements are carried out to provide the basic input data for the theoretical models. These data consist primarily of chemical kinetics rate constants and photochemical cross-sections. In addition, spectroscopic data of atmospheric constituents are acquired for the interpretation of atmospheric measurements. Development of calibration standards is also a vital aspect of this program.

(3) Theoretical Studies and Data Analysis:
The two principal activities in this area of the program are the development of a hierarchy of models to describe the chemical, radiative, and dynamical processes which control the chemical composition and physical structure of the present atmosphere and to predict possible future changes, and the analysis and interpretation of large satellite data sets and other major field measurement campaigns.

Some specific thrusts in the near term include:

(1) A vigorous effort to understand the processes responsible for the recent decrease in the ozone column above the Antarctic in springtime. This effort is strongly supported by the NSF Polar program, NOAA, and by the CMA. A campaign of ground-based field measurements, in conjunction with satellite observations, was carried out last year. Analysis of the data is currently underway. An aircraft and ground-based field measurement campaign for August 1987 is being planned. NASA is planning to base two aircraft, an ER-2 with an altitude ceiling of 21 kilometers and a DC-8 with an altitude of 13 kilometers, containing approximately 16 state-of-the-art in situ and remote sensing instruments at Punta Arenas, Chile for a six week period starting about the third week of August.

(2) The final design and initial implementation of "A Network for the Detection of Stratospheric Change." This network is being designed to provide the earliest possible detection of changes in the chemical composition and physical structure of the stratosphere, and the means to understand them. Successful implementation of this system will require cooperation and coordination at both the national and international level. Discussions on the implementation of this system are currently in progress. This program has been endorsed by the UNEP scientific panel engaged in negotiation of a protocol to regulate chlorofluorocarbons.

(3) The Upper Atmospheric Research Satellite (UARS), for which the launch date is uncertain due to Challenger manifest changes but is currently scheduled for 1991, will provide the first simultaneous measurements of the atmospheric distributions of oxygen, hydrogen, nitrogen, and chlorine species, coupled with measurements of temperature, dynamical quantities such as winds, and energy inputs and losses. These

measurements will allow us to study the coupling between the chemical, radiative, and dynamical processes which control the chemical composition and structure of the stratosphere, and, in particular, the amount and distribution of ozone, in a manner never before possible, the mechanisms responsible for atmospheric variability, and the response of the stratosphere to changes in external factors such as solar activity and natural phenomena such as volcanic eruptions.

(4) Atmospheric concentration measurements and flux measurements of biogenic gases predicted to control atmospheric ozone from representative ecosystems in order to understand past and future trends in the composition of the atmosphere. Particular emphasis is on methane, which also plays an important role as a greenhouse gas.

5) The continued development of theoretical models which can simulate the coupling between the chemical, radiative, and dynamical processes that control the chemical composition and structure of the atmosphere.

These research activities are ongoing, multiyear efforts aimed at reducing some of the current uncertainties in our scientific understanding of these issues. We expect that progress in most areas will be steady and that many of the key uncertainties should be significantly reduced within a decade. We expect very significant progress on the issue of Antarctic ozone within a few years, but understanding the coupling between the chemical, radiative, and dynamical processes that control the chemical composition and structure of the atmosphere will require the UARS data before much more progress is made. If the "Network for the Detection of Stratospheric Change" is implemented, then significant progress on detecting and understanding the causes of changes in stratospheric composition should be expected within a decade. But a fuller understanding of the factors which control atmospheric ozone will require a new initiative in the Earth sciences because the ozone issue is not simply a problem of understanding the atmosphere, but requires an intimate knowledge of the oceans and land.

B. THE TROPOSPHERIC CHEMISTRY PROGRAM

The goal of the tropospheric chemistry program is to develop an understanding of global tropospheric chemistry and assess the susceptibility of the global atmosphere to chemical change. Tropospheric chemistry plays an extremely important role in biogeochemical cycles, governing (in conjunction with dynamical processes) the concentration distribution of atmospheric trace species and altering the chemical composition in which trace elements move through the atmosphere. It is a crucial science in the evaluation of the effects of atmospheric chemical change on the global hydrological cycle, the cycling of nutrient compounds through the environment, the accumulation of infrared active gases in the atmosphere, the acidity of rain and snow, and the depletion of ozone in the upper atmosphere by chemical species that have their sources and sinks in the troposphere.

The objectives of the NASA Tropospheric Chemistry Program are to:

(1) Develop techniques for remote and in situ measurement of the concentrations and fluxes of key tropospheric species

(2) Determine tropospheric meteorological/chemical influences on the atmosphere as a whole, particularly the stratosphere;

(3) Understand the chemistry of global tropospheric species and the causes of changes in chemical composition;

(4) Develop a realistic general circulation model of the global troposphere with chemistry included for use in field experiment design and data analysis;

(5) Develop and implement a strategy for chemical measurements from space platforms.

Measurements of the most important chemical species involved in global biogeochemical cycles require instruments capable of operating in the parts per trillion range (for NOx) and even the parts per quadrillion range (for HOx) against the natural atmospheric background and on aircraft and/or at complex ground sites as diverse as the tropical rain forest and the arctic tundra. For flux measurements by eddy correlation a time response of 10-20 Hz is required for boundary layer experiments, and a time response of 1 - 2 Hz is required for experiments on troposphere/stratosphere exchange. Development of the capability to meet these measurement needs is a major task and a crucial one for future progress.

Projects aimed at instrument development are being done within the NASA program concurrently with field programs that utilize available instruments to study atmospheric chemistry in environments of prime interest, such as the tropics, agricultural wetlands, and the troposphere/stratosphere interface. In many cases the instruments involved in the central experiments in the field projects are the results of the instrument development and validation elements of the NASA program.

In order the achieve the program's goal fairly large scale field projects must be carried out within the next decade. To conduct tnese experiments in the most efficient manner a general circulation model is required, and is under development, to provide a calculation of the large scale dynamical processes that transport reacting and non-reacting species through the atmosphere. This model should allow for inclusion of such processes as chemistry inside clouds and the role of cloud chemistry in transporting chemicals within the atmosphere. It would serve as a tool for planning the optimum field experiments and synthesizing the data from them. Simpler, one and two dimensional models with parameterized transport are also under development and refinement to aid in field experiment design and analysis.

The current program elements are designed to support directly the goals and objectives described in the preceding section. they are as follows:

(1) Modeling and Data Analysis - supports the continued development and application to experiment planning and data analysis of 1- and 2D photochemical models with parameterized transport and the development of a general circulation model with chemistry included.

(2) Field Measurements - Supports field measurements with existing, proven instrumentation and necessary improvements to research platforms to carry out field measurement and instrument intercomparison projects. These field measurements have been collectively named the Global Troposphere Experiment (GTE) and constitute the major thrust of the program. They are organized into Atmospheric Boundary Layer Experiments (GTE/ABLE) and Chemical Instrumentation Test and Evaluation (GTE/CITE) projects.The first group focus on source/sink studies, while the second focus on instrument development and validation. Addition of an exploratory series aimed at tropical chemistry and transport is planned.

(3) Laboratory Studies - Supports a small effort in homogeneous, gas-phase chemical kinetics and laboratory work aimed specifically at measuring energy transfer cross sections and spectroscopic constants needed by some of the higher technology instruments under development.

(4) Instrument Development - Supports research aimed at developing the instruments needed to meet the measurement goals of the program.

The current program thrusts are:

(1) A GTE/CITE-3 sulfur species and ammonia intercomparison experiment to be conducted from Natal, Brazil in 1989 to build upon the highly successful CITE-1 and CITE-2 experiments that intercompared instruments to measure OH, CO, and several nitrogen species at concentration levels found in the clean troposphere;

(2) Analysis of the CITE-2 data on odd nitrogen species to determine the abundances and partitioning of the major reactive nitrogen species in the continental and remote oceanic troposphere;

(3) Analysis of the rich data base acquired in the highly successful ABLE-2A and ABLE-2B experiments in Brazil in 1985 and 1987 to obtain quantitative information about the sources and sinks for important trace gases and aerosols located in the tropical rain forest and investigate the causes of high CO concentrations off the coast of Brazil observed in two shuttle flights. The expeditions, which involved aircraft, instrumented towers, tethered balloons, and boats on the Amazon River were the largest ever mounted to study the atmospheric chemistry of the Amazon Basin.

(4) Development of second generation OH detection instrument with sufficient sensitivity for global measurements from aircraft.

(5) Limited enhancements in heterogeneous chemistry in laboratory and field measurements.

(6) Continued discussion with the People's Republic of China about a joint boundary layer experiment over agricultural wetlands in China;

(7) Planning for a DC-8 based series of experiments over the tropical Atlantic and Pacific Oceans to follow the distribution of gases from the Amazon Basin and the ocean upwelling region off the coast of Peru, the latter mission to be preceded by intensive studies of the source strength of the upwelling with the NASA Electra in a GTE/ABLE-4 project

Tropospheric chemistry offers an opportunity for major progress in understanding the stratosphere, understanding biogeochemical cycles, buildup of infrared gases in the atmosphere, and significant breakthroughs in remote sensing when enhanced funding is found to accelerate the pace of the critically needed instrumentation, the science and technology needs for which have been well developed in a series of NASA planning workshops. Enhanced funding would also allow increase in the scope and frequency of expeditionary field experiments, such as GTE/ABLE and GTE/TRACE, and a great improvement in long-term monitoring activities. The NAS/NRC has recommended that a major international program in tropospheric chemistry be undertaken that would require strong participation by NASA, NSF, and NOAA. Current coordination among these agencies is already quite strong, providing a good basis for enhanced programs in tropospheric chemistry in all three agencies, each of which brings unique capabilities to the overall program.

(2). CLIMATE RESEARCH PROGRAM

The long-term objective of the NASA Climate Research Program is to conduct research to improve our understanding of the radiation and dynamical processes which govern the climate system of the Earth and to observe the physical properties of the system which influences its change. The unique aspect of the NASA program is its use of space technology to address these objectives. The program includes research on: establishing the long term data base required for climate studies; analyzing the data base; developing models to diagnose and describe the climate system; and developing special observing capabilities to address problems unique to climate.

Understanding the basic nature of solar and Earth radiation and its transfer through the atmosphere to and from the land surfaces and oceans is one of the fundamental goals of climate research. Monitoring and analysis of the sun and components of the Earth's radiation budget and their effects on the atmosphere, land and oceans are crucial to developing this understanding. They will be used to diagnose the present (and near future) state of the climate, for the formulation of empirical prediction techniques and, ultimately, for the development and validation of global and regional climate prediction models. Insights gained in studying the Earth's radiation budget are also vital to developing confidence in prediction of the long-term effects of man's influences such as CO2, ozone, and aerosols, as well as the effects of natural phenomena such as volcanic eruptions.

Recognizing the importance of this research in improving our understanding of the mechanisms controlling climate variations, the National Climate Program has established a principal thrust in Solar and Earth Radiation and has assigned NASA lead agency responsibilities for organizing and conducting a long-term broad-based research program of observations and analysis. The broad nature of this activity has required close coordination with other federal agencies having overlapping programmatic interests, in particular NSF, NOAA, and DOE, as well as with the international scientific community through the World Climate Research Program.

Recent precise measurements from the NASA Solar Maximum Mission (SMM) and the Nimbus-7 Earth Radiation Budget (ERB) experiment have established that the total solar radiation flux, also known as the "solar constant," above the atmosphere is indeed variable. Since 1979, sensors on both spacecraft independently observed variations of the solar flux as large as 0.25 percent on time scales from days to weeks. The amplitude of observed monthly and yearly variations, although smaller, nevertheless have the potential for affecting climate and, as such, are high priority monitoring objectives. Additional data are now becoming available from the NASA Earth Radiation Budget Experiment (ERBE), which also confirm the observed solar flux variability. Future plans are to incorporate a similar instrument on the Upper Atmospheric Research Satellite (UARS), which will continue these measurements into the 1990's. Periodic Shuttle sortie flights are planned to verify the performance of the free-flyer measurements and to intercompare other instrument designs.

The study of the role of clouds in climate has been given a particular emphasis in NASA-sponsored climate research. Clouds have a very strong modulating influence on the radiative energy exchange between the atmosphere and the upper and lower boundaries. They control the amount of solar energy absorbed by the climate system as well as the longwave energy radiated to space. The partitioning of the solar energy input between the atmosphere and oceans is also highly dependent upon cloud cover. These effects are extremely important on climate time scales and are critical to our understanding the effects of long-term CO2 building in the atmosphere.

The first step necessary in understanding the role of clouds is to develop a climatology of the important cloud parameters over a period which reveals the diurnal, seasonal, and

interannual variations. This requirement is being met through NASA's central role in the International Satellite Cloud Climatology Project (ISCCP), organized as a part of the World Climate Research Program (WCRP). The ISCCP, which began in 1983, routinely collects and processes cloud image data from the international array of operational meteorological satellites operated by the U.S., Japan, India, and the European Space Agency, to produce a five-year global cloud data set.

It is also essential to develop cloud models which incorporate the basic physical processes which contribute to the generation, maintenance and dissipation of clouds. In order to gather the data to test these cloud models, NASA, along with NSF, NOAA, and DOE, is conducting a series of field experiments in which the relevant atmospheric and cloud parameters will be measured in detail over a number of cloud formation cycles and a variety of synoptic weather conditions leading to the generation of various cloud types. This effort is a part of the First ISCCP Regional Experiment (FIRE) which began earlier this year and will continue through 1989.

Whether viewed as part of the WCRP, or as basic elements for the proposed International Geosphere/Biosphere Programs, these experiments will not only benefit oceanography and climate, but will also make fundamental contributions to Earth Science. In addition, the understanding gained from these experiments will assist in the design of future operationally oriented ocean and climate observing systems.

(3). OCEANS PROGRAM

Two recent events have emphasized the ocean's importance in global climate: the disastrous 1982-1983 El Nino, which caused billions of dollars in damage and considerable loss of life, and the potentially harmful effects of increasing CO2 levels in the atmosphere due to the burning of fossil fuels. We now know that our ability to understand and ultimately predict the droughts and flooding associated with a severe El Nino or with the warming predicted from a CO2 increase is severely limited by a lack of ocean measurements. New global information available from satellites, coupled with data from the interior of the ocean, will meet this need. A second limitation is the lack of data on the distribution of global cloudiness. An ongoing international research project will address this deficiency.

Reports from the National Academy of Sciences and studies by various government agencies all point to the serious consequences of a global warming. They also stress the need for better understanding of the problem, particularly the role of oceans and ice cover in either modulating or amplifying the warming trend. The existing climate models used for predicting carbon dioxide induced warming oversimplify interactions between the atmosphere and the ocean. Any significant improvement will require many more observations leading to a better understanding of oceanic and atmospheric behavior.

For the oceans, the crucial measurements include ocean circulation, sea surface winds and temperatures, biological productivity, and the polar ice cover. Biological productivity can be determined through measurements of ocean color, which depends primarily on the photosynthetic pigments (chlorophyll) contained in marine plants. Since these plants are the basis of the marine food web, measurements of their amount and distribution are critical to obtaining a better understanding of biological and chemical processes, including the cycling of carbon through the oceanic ecosystems. All of these measurements should be well distributed over the globe and made regularly to determine natural variability. Such coverage can be provided only from a space-based program operating over a period of several years.

NASA plans for the decade of the 1990's include the flight of a scatterometer (for sea surface winds) aboard the Navy Remote Ocean Sensing System (NROSS) satellite; a dedicated altimeter mission for ocean currents, the Ocean Topography Experiment (TOPEX), and a color scanner (for ocean biological productivity) aboard a platform of opportunity. In order to exploit the potential offered by this next generation of oceanographic sensors, we are working with the NSF, U.S. Navy, and NOAA, as well as with our international partners to plan a set of comprehensive at-sea experiments. Two examples are the Tropical Ocean Global Atmosphere and World Ocean Circulation Experiments being organized under the World Climate Research Program (WCRP).

(4). LAND PROCESSES

It is well known that climate fluctuations and trends may have effects on society--on a regional as well as on a global scale. Land observations from satellites will also become part of a data base for monitoring changes of the surface, for instance of vegetation and snow cover, and of the climate of the surface of the earth. Such monitoring is particularly urgent at the present time due to man's increasing sensitivity to climatic fluctuations and the possibility that man's activities may have climatic consequences.

As stated earlier, the continued burning of fossil fuels may lead to increases in atmospheric carbon dioxide large enough to have a significant global climate impact. Changes in agricultural practices may lead to regional desertification or deforestation, which can lead to regional changes in the energy and moisture budgets. Draining wetlands can cause large changes in methane production, another important gas related to global temperature changes. It is clear that global, continuous monitoring of such anthropogenically induced changes, as well as naturally occurring variations, can only be obtained from satellites.

NASA is encouraging the development of the International Satellite Land Surface Climatology Project to develop methodologies for deriving quantitative information concerning land surface climatological variables from satellite observations of radiation reflected and emitted by the earth. Such quantitative information is required to:

(1) Monitor global scale change of the land surface caused by climatic variations or by human activity;

(2) Further develop mathematical models designed to predict or simulate climate at various time scales;

(3) Permit inclusion of land surface climatological variables in diagnostic and empirical studies of climate variations.

The time is appropriate for conducting such studies because of the increasing sophistication both of remotely sensed observations from space and the development of improved climate and medium range weather prediction models.

The land surface variables of interest and potentially obtainable more or less directly from satellite observations are vegetation cover, albedo, solar radiation, longwave radiation, skin temperatures, emissivity, soil moisture, and snow cover and depth. The work may be divided into two parts in present research.

(1) Evaluation of existing satellite data collected in the last fifteen years to determine their usefulness in detecting climate related fluctuations or man-induced changes in the surface of the Earth.

(2) Development and validation of methods to convert satellite-observed radiances to surface climatological variables. The validation effort will require intercomparison of satellite-derived quantities with simultaneous ground- and aircraft-based measurements, to be carried out in field programs in selected areas.

The first investigators in the first part of this work, retrospective studies, were selected in response to a letter issued in January 1985. The first field experiment is currently being held at the Konza Prairie Grassland in Kansas. This site is managed by Kansas State University in conjunction with the National Science Foundation.

An experiment with somewhat similar aims was conducted in France in the summer of 1986 under the auspices of the World Climate Research Program. NASA sent a C-130 aircraft equipped with various radiometers for remote sensing for a six week period during this experiment. NASA also assembled a team of investigators from NASA, USDA, and various universities to analyze the resultant data.

The land surface climatology work being led by NASA should lead to important new insights as to the interactions between the land and the atmosphere, and thus of how the Earth functions as a global system.

(5). INTERDISCIPLINARY RESEARCH

NASA established an Interdisciplinary Earth Science Research Program in 1984. Three areas of research were chosen for initial study representative of the kind of research that needs to be performed in a Global Change program. These are particularly important areas of research in which progress can be made. The three areas are:

(1) a program of research to understand the reasons for the increasing trend in the atmospheric concentration of methane, and the long-term consequences of it for climate and ozone if it continues;

(2) a land-surface climatology program which is aimed at determining the extent to which changes are taking place in climatologically important properties of the land surface, to quantify those changes in physical and biological terms, to determine the important processes which control the changes, and to determine the overall stability of the land-climate system; and

(3) an ocean basin scale carbon flux program which will develop a better understanding of the magnitude, variability, and fate of carbon fluxes in th oceans on an ocean-basin scale, and the role of oceanic carbon fluxes in global scale biogeochemical cycles and climate.

FUTURE NASA RESEARCH PROGRAMS RELATED TO GLOBAL CHANGE

EARTH OBSERVING SYSTEM

Eos, the Earth Observing System has been recognized by the Earth System Science Committee as the center piece of NASA's activities with respect to understanding global change. Space offers a unique perspective of the Earth from which consistent measurements can be global observations can be made. By capitalizing on increases in spacecraft size and capability, improvements in remote sensing instrumentation, and advances in data and information systems Eos, if approved, will be able to measure many parameters of the Earth system in new ways which are consistent with the time and space scales of the phenomena under study. Eos will also provide a sustained capability which can extend the time horizons of observations now underway or which will be initiated by

the missions preceding Eos. The atmosphere, oceans, and land surface will be characterized in a comprehensive manner covering both localized targets and the whole planet with frequent measurements. Eos data will be essential for answering research questions on the global cycles of water and the biogeochemical elements essential for life, the flow of external and internal energy through the Earth system, and specific topics in virtually all of the traditional disciplines of Earth science.

NASA is proceeding with planning for the Eos mission and with development of certain elements within the Eos program. Specifically, Eos will make use of the polar platforms being developed as part of the international Space Station effort. The block 1 portion of the Space Station program which is now underway includes a U.S. polar platform for carrying Eos payloads. The European Space Agency is actively considering provision of a European polar platform as part of their contribution to the initial Space Station complex and NASA is strongly encouraging them to do this. NASA also has funding to develop two facility class instruments which form a significant part of the eventual Eos payload, namely the High Resolution Imaging Spectrometer and the Space Imaging Radar which will initially fly on the Space Shuttle. A number of our on-going flight mission developments are laying the foundation for the Eos instrumentation, since one of the keys to understanding the Earth is long-term continuity in datasets of key Earth variables and this is a vital part of Eos.

The Earth science community has recognized that operational datasets such as those collected from satellites by NOAA represent a significant contribution to long-term, consistent measurements of the Earth. This specific character of operational data acquisition is now shared by many of the research measurements which are to be developed. On this basis, NASA has worked extensively with NOAA to harmonize the planning for future research and operational systems. Our goal is to improve the utility of operational data to the research community and to make research instrument development more readily available to the operational activities of the government. NOAA and NASA are currently planning to share the polar platforms being provided through the Space Station program by flying a combined research and operational payload. The NOAA payload will meet several specific requirements of the research community for Eos including atmospheric sounding, ozone monitoring, data collection and location services, and direct broadcast capabilities. NASA's payload will include several new capabilities designed to meet the research needs in Earth science. The operational community will have this data available and can begin to make use of it in developing new operational products.

The Space Station planning at NASA is being done in concert with Japan, ESA, and Canada as potential international partners. This has helped to stimulate a strong international planning effort to prepare for Eos. Representatives of the Earth observations offices of the Space agencies involved have been meeting for over a year to coordinate the plans for the provision of instruments and science investigations as part of the Eos effort. NOAA and Eumetsat delegates have been included to broaden operational cooperation and coordination as well. This international Coordination Working Group has developed scenarios for how to allocate the required instrumentation among the initial NASA and ESA polar platforms. These plans include substantial instrument contributions by Japan and Europe to the U.S. platform payloads and by NASA and NOAA to the ESA and Japanese platform payloads. Considerable cost sharing appears to be possible. NASA, ESA, and Japan are also planning the coordinated release of Announcements of Opportunity this coming January to solicit instruments and other scientific investigations using Eos data from the international Earth science community. The selecting officials of all three partners are committed to coordinating our choices of payloads for eventual development. Broad international participation in the Global Change effort is required if essential exchanges of

ground based data from within national borders is to be achieved. This international coordination in space is a key step toward this goal.

SUMMARY

In summary, given what we know about issues such as the ozone and greenhouse warming we should recognize that we are conducting a global scale experiment on the Earth's atmosphere without a full understanding of the consequences. Understanding these and related issues should clearly be a priority for the scientific and policy communities. This will require a comprehensive coordinated national and international research effort. NASA is firmly committed to working closely with all other federal agencies and international organizations. Wise policy decisions require an improved understanding of the way in which the Earth's environment varies naturally and in response to human activities. Of course, NASA understands the fiscal realities that confront us, and will continue to evaluate our Earth System Science efforts in the context of the rest of our space program.

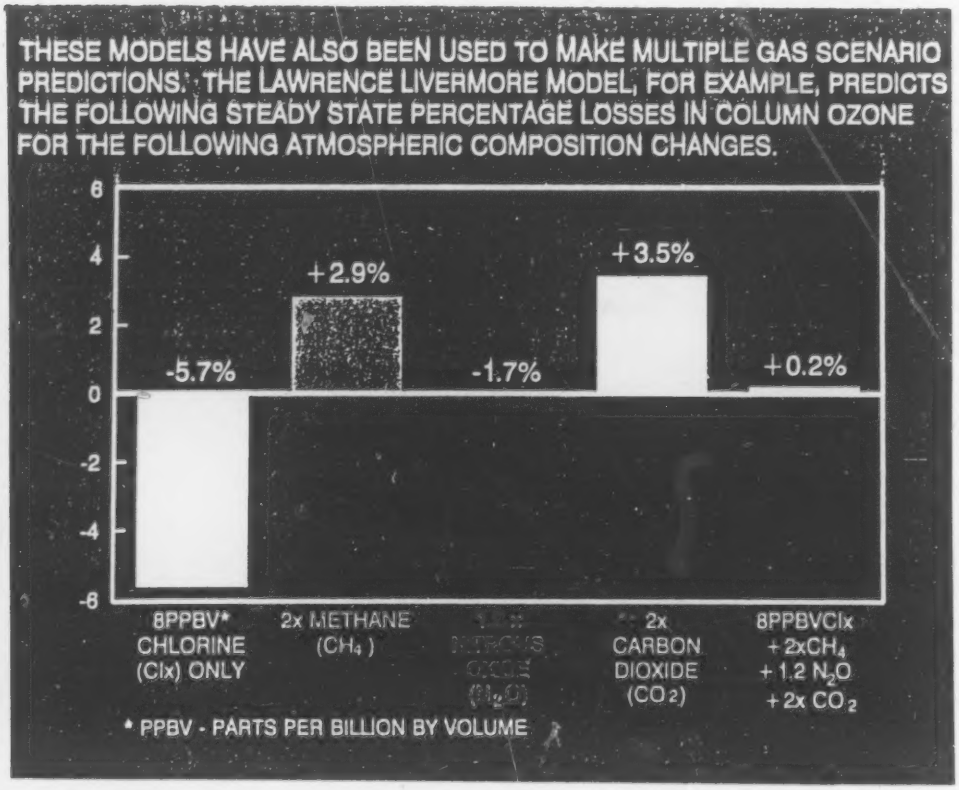

THESE MODELS HAVE ALSO BEEN USED TO MAKE MULTIPLE GAS SCENARIO PREDICTIONS. THE LAWRENCE LIVERMORE MODEL, FOR EXAMPLE, PREDICTS THE FOLLOWING STEADY STATE PERCENTAGE LOSSES IN COLUMN OZONE FOR THE FOLLOWING ATMOSPHERIC COMPOSITION CHANGES.
6
4
2
0
-2
-4
-6
-5.7%
+2.9%
-1.7%
+3.5%
+0.2%
8PPBV* CHLORINE (Clx) ONLY
2x METHANE (CH_4)
2x CARBON DIOXIDE (CO_2)
8PPBVClx + 2xCH_4 + 1.2 N_2O + 2x CO_2
* PPBV - PARTS PER BILLION BY VOLUME

Figure 1

Effects of 80% compliance with freeze, remaining 20% grow at 3% or 5%/year

Effects of emission reductions in complying 80%:
--20% cut in 1992 followed by 30% cut in 1997
--noncomplying 20% continue to grow at 3% or 5%

Effects of delaying emission reductions by 5 years (to 1997 and 2002)

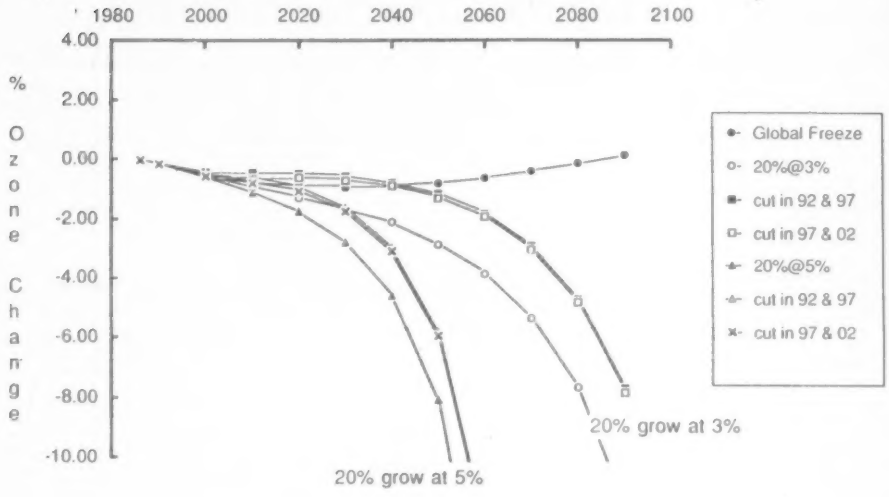


Figure 2

CHANGES IN OZONE DISTRIBUTION FOR A TRUE GLOBAL FREEZE OF ALL CFCs

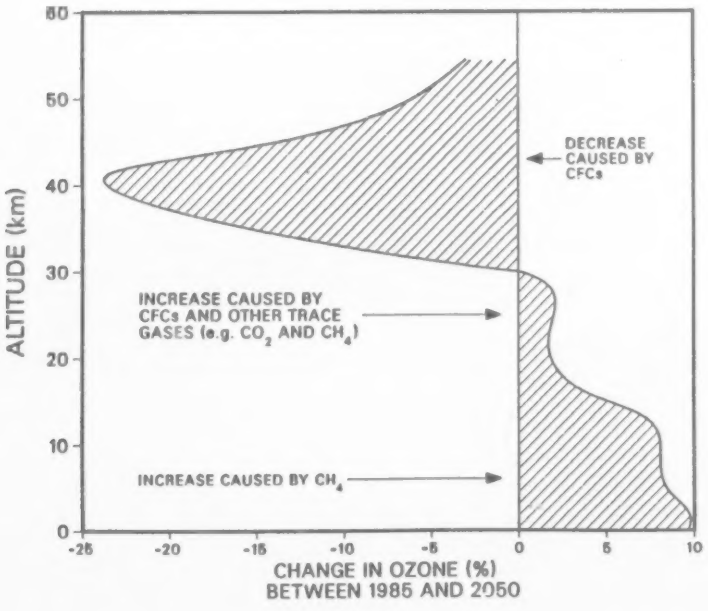
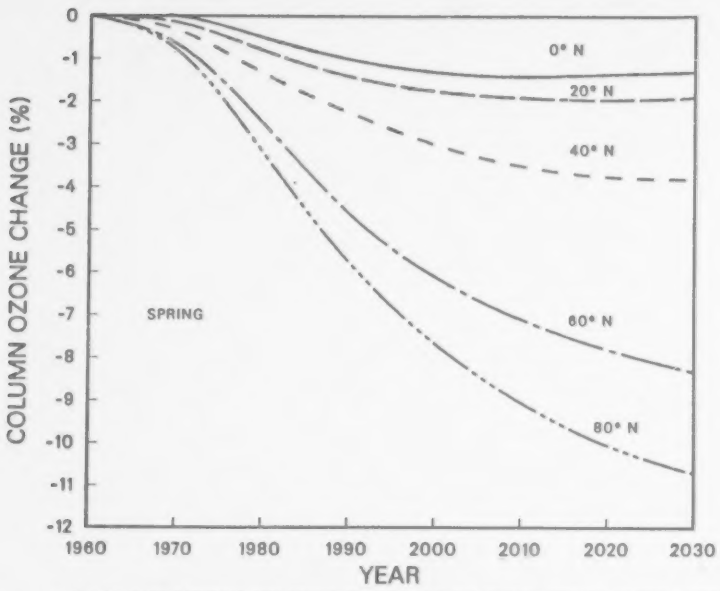


Figure 3

CHANGES IN COLUMN OZONE AT DIFFERENT LATITUDES FOR A TRUE GLOBAL FREEZE



• ALL 2D MODELS PREDICT DEPLETIONS GREATER THAN THE GLOBAL AVERAGE AT HIGH LATITUDES, HENCE BASIS FOR CONCERN FROM SCANDANAVIANS, ETC.

Figure 4

GLOBAL OZONE MEASUREMENTS
COLUMN OZONE

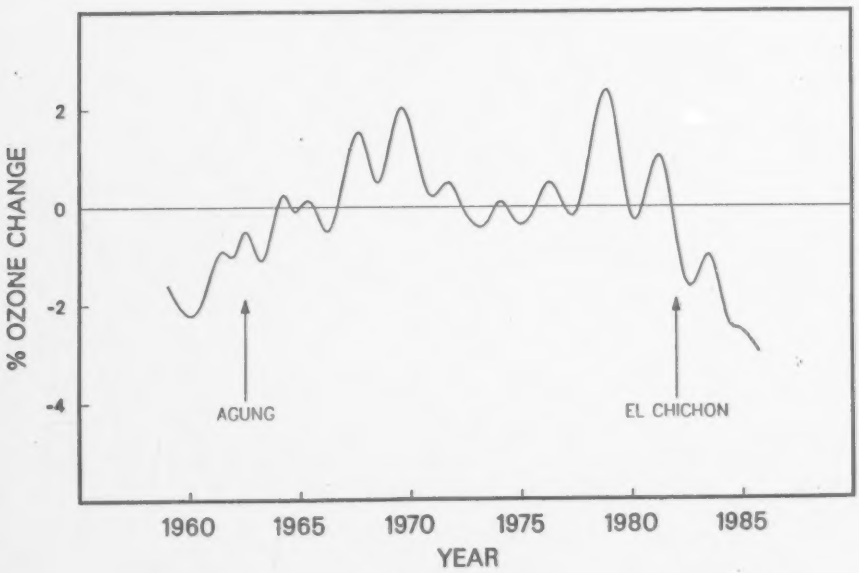


Figure 5

GLOBAL OZONE MEASUREMENTS
VERTICAL OZONE DISTRIBUTION
DECADAL TREND 1970-1980

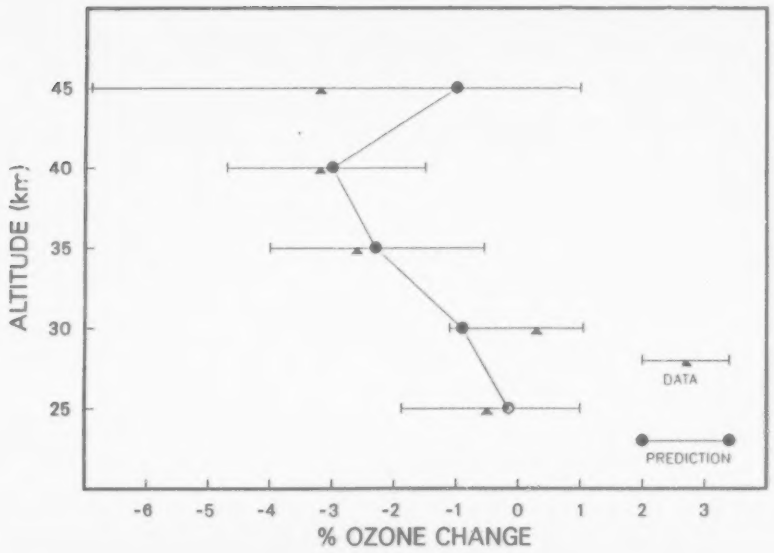


Figure 6

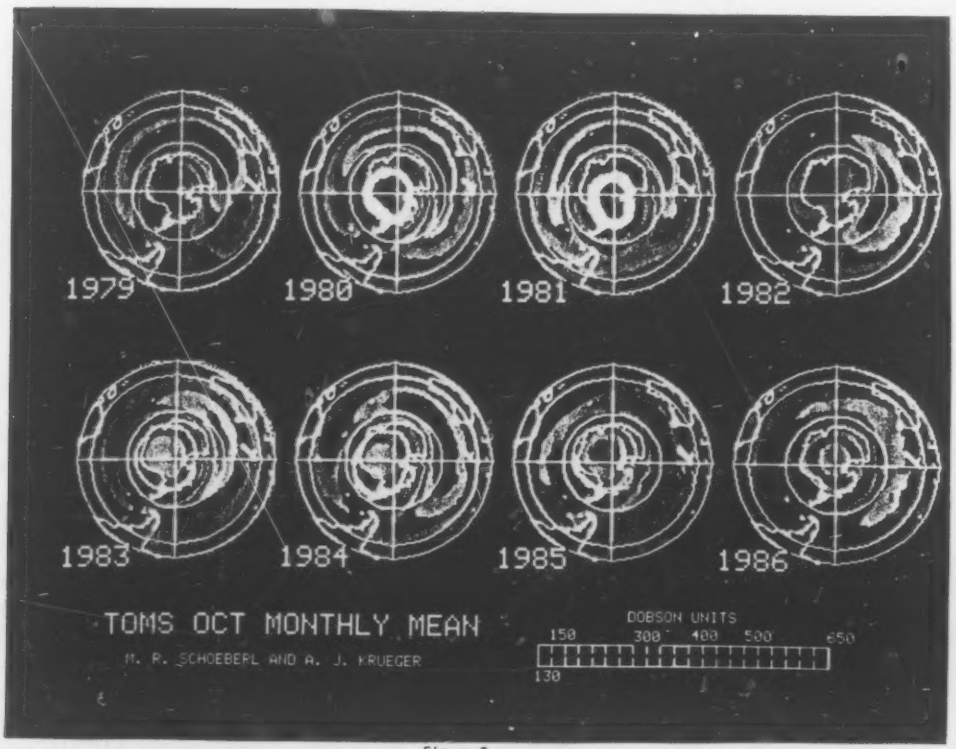


Figure 7

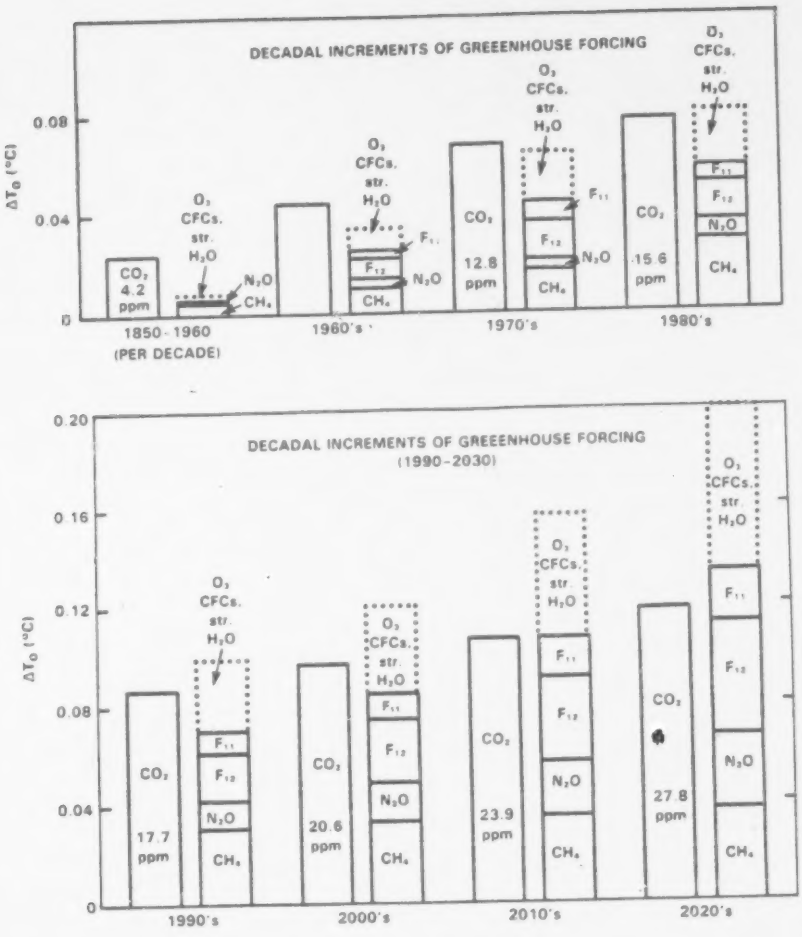


Figure 8. Decadal additions to global mean greenhouse forcing of the climate system. $(\Delta T_s)_0$ is the computed temperature change at equilibrium ($t \to \infty$) for the estimated decadal increases in trace gas abundances, with no climate feedbacks included.

Responses to written questions submitted by Chrm. Hollings.

Question 1: The satellite data flow is expected to increase by two orders of magnitude within the next decade. A recent GAO report titled "NASA's Use of Information Technology" touched on the concerns of the scientific community with respect to processing and archiving these large amounts of data.

- What efforts are underway at your agency and others to address these problems?

- If storage and processing facilities are not adequate, what happens to the satellite data transmitted?

- How are these data made available to researchers?

Answer 1: OSSA's information systems program addresses these science data management concerns, with particular attention to exploring technologies needed for new high-rate high-volume instruments. We are currently evaluating several very high performance computing systems, in addition to our Class VI supercomputer, for massive parallel processing of image and radar data. Our data management work includes research in manipulation and management of large data sets, as well as research in data compression techniques. Our data system testbeds have been evaluating magnetic and optical media under different software environments using data from a variety of science instruments. These activities are fully coordinated with related research & technology programs conducted by NASA's Office of Aeronautics and Space Technology, and with programs in the National Science Foundation and the National Bureau of Standards.

Plans to provide adequate processing and storage requirements have already begun. We hope that this planning will lead to the future initiation of special high-speed computing facilities for high-volume radar and imaging data, and a new distributed information system called the Earth Observing System Data and Information System. New technologies including optical tape and fine-grained supercomputers will also be applied.

Our data are readily available to researchers though OSSA data centers via magnetic tape, optical disks, high-speed computer networks, as well as in hardcopy form. A new central directory and distributed catalog system under development will further aid researchers to locate data of interest.

Question 2: NASA's space science program has been through some difficult times since the loss of the Challenger. That single event had a tremendous and immediate impact on the entire agency, but we found that space science was affected perhaps more than any other area of NASA. Many of our premier science missions were postponed, some many years after their projected flight. The full effects of the Challenger have still not been measured on the space science program, but clearly it had an impact on what we are discussing today.

- Would a further delay in shuttle launches have any impact on NASA's efforts in Earth system research? For example, what impact would you see if the shuttle is grounded for another six months or a year or if the flight rate is very slow to recover?

- How has the delay in, and limited number of, Spacelab missions affected NASA's contribution to studying global climate change?

Answer 2:

- The actual impact against Earth system research from a further delay in Shuttle launches would depend on what the new manifest would be. For example, if the Upper Atmosphere Research Satellite (UARS) program was forced to slip, it would probably have to opt for a one-year delay even if only a 6 month slip were offered. Scientifically, UARS requires two northern hemisphere winters data so that a slip in launch could have to be on an annual basis rather than a seasonal basis. Another near-term mission, the Shuttle Imaging Radar-C (SIR-C), is currently hoping for a launch concurrent with the German X-SAR in the mid-1991 time frame, and coordinated research efforts and planning are underway. If a new manifest chose to slip the planned SIR-C out further, the research community would be similarily impacted due to no new data, and various coordinated efforts could become fragmented. Alternatively, TOPEX, and NROSS (Scatterometer) are not baselined for Shuttle launch now, so those communities would be more protected from impact.

- The delay in and limited number of projected Spacelab mission does not directly impact efforts towards global climate change except as outlined above in the ATLAS series. OSSA has rightly advocated a dedicated use of Spacelabs for those missions which require manned attendance for operations or servicing such as in areas of materials research, life sciences, and selected areas of interactive space plasma physics research. The fact that various climate related or Earth radiation budget sensing satellites have been launched by Shuttle in the past does not mean that such payloads require orbit insertion by the Shuttle, but those currently designed for Shuttle interface still must fly that way. NASA is making every effort to maintain continuity in the research programs by selecting the launch vehicle appropriate to the mission. The Active Cavity Radiometer sensor as a part of the UARS complement of instruments, of course, is impacted by a slip in current manifesting as is SSBUV and other calibration payloads as discussed above. Other climate related sensors appear to be protected against fluctuations in the Shuttle or Spacelab manifest.

Question 3: With respect to the polar platform, it is my understanding that NASA has slipped the launch date for the platform from 1994 to 1995. Apparently, NASA believes that it will take longer than seven years to develop the EOS instruments for the platform.

- What is the exact status of the polar platform?

- Have costs of the polar platform increased to the same extent that the overall cost of the space station has risen?

- If indeed the EOS instruments are the cause for the delay, can you tell what is involved in the development of these instruments that would cause such a delay in flight?

Answer 3:

- NASA has completed its Phase B design of the Polar Platform (carrier) and is ready to start detailed planning for Phase C/D. A Source Evaluation Board is currently in process for the platforms with a decision expected by the end of the year. On the instrument side, detailed planning and study of an appropriate payload complement has been iterated over the past several years between OSSA, the Office of Space Station, NOAA, the respective science communities and the various member states of the European Space Agency. An Announcement Of Opportunity for the Earth Observing System is planned to be released to the research community early in calendar year 1988 from which an initial payload and team investigator selection will be made in time to support readiness for a new start status for EOS by fiscal year 1991.

- The platform costs have not changed substantially from the original projected costs and are currently assumed to be within about 15 to 20 percent. From a user perspective, the platform part of the Space Station program has remained relatively stable. Instruments usually do not need as long a Phase B study as to large facilities, however, because of programmatic requirements within OSSA to support a broad spectrum of science opportunities, a phasing of programs dictates that EOS not be suggested for new start status before fiscal year 1991. Hence, a 1991 new start supports a 1995 launch better than a 1994 launch. The proposed schedule calls for 39 months for development of most of the instruments and 18 months for integration into and of the platform. OSSA does not see the delay as ideal but has certainly been able to plan use of the time to best accommodate the needs of the Earth observing research community, and we are moving into development as fast as possible.

Question 4: The TOPEX satellite is scheduled to be launched by Ariane. I understand that Ariane has not successfully launched a mission in over a year and has a large backlog of missions.

- What will be the effect of Ariane's current difficulties on the TOPEX launch date?

- Can TOPEX be launched on a U.S. System such as a Titan Expendable Launch Vehicle (ELV)?

Answer 4: Currently, we see no effect on the TOPEX planned launch date of December 1991 as a consequence of the current Ariane difficulties. The last Ariane launch attempt was in May 1986 (V-18), which resulted in a failure due to problems in the third stage ignition system. This system has subsequently been redesigned and successfully tested, and Arianespace has recently resumed launches. The first test launch of the Ariane 4, is planned for this coming January. This will be an important event, as TOPEX plans call for the usage of an Ariane 4. However, even if there are unexpected difficulties with the Ariane 4 development activity, TOPEX is currently not planned for flight until almost four years

after the first planned Ariane 4 launch. Given the fact that it is imperative that the TOPEX launch be successful if Arianespace is to gain the benefit (added credibility) of being the first foreign launch vehicle used to launch a NASA satellite, and the almost four years available to solve problems, it is highly unlikely that they will do anything other than put their best possible effort into insuring a successful TOPEX launch. In this regard, there have been recent discussions among NASA, CNES, and Arianespace, regarding the allocation of a specific Ariane 4 for the TOPEX launch. As a consequence of these discussions, agreement in principle has been reached to manifest TOPEX for a launch in December 1991, and it is our understanding that the next Ariane manifest released will show TOPEX that way. In the meantime, NASA and CNES are working jointly to prepare a formal DUA (the Ariane equivalent of a Space Flight Request) by the end of 1987. As an aside, cooperation by CNES and Arianespace with NASA regarding launch vehicle performance analysis, planning, and interface definition has been outstanding, further evidence that the French intend to give their best effort to TOPEX.

In the event that unexpected difficulties were to arise with the Ariane 4 development effort, the results of an earlier study by the TOPEX Project suggest that:

1- The Tital 34D Transtage will do the job with about 50 percent overkill in terms of lift capability, and there is a good fit with respect to the shroud.

2- The Atlas Centaur has the lift capability but some satellite repacking (by folding up some antennas, for example) would be required to fit under the shroud.

3- The Delta II could also do the job, but like for the Atlas Centaur, there is a shroud problem.

4- The Titan II does not have adequate lift capability.

Thus there are several feasible possibilities regarding the possible launch of TOPEX using an U.S. ELV should that need arise.

Question 5: NASA's space science programs face stringent budgetary constraints. Consequently, NASA's ability to pursue a diverse and multi-faceted science effort has been questioned.

- Does the U.S. Global Change Program have a high enough priority within NASA to provide the aggressive, sustained effort throughout the next ten to fifteen years that is required in the IGBP?

- How can NASA assure constant funding to this effort in the face of other priorities such as interplanetary missions, astrophysics, life sciences and materials processing, Hubble Space Telescope and other important programs?

- Of the three missions that you have identified as being part of the Global Climate Change program - TOPEX, NROSS, and EOS - which is the most important and critical to the success of the IGBP?

Answer 5:

- The anticipated NASA participation in the U.S. Global Change Program is through the proposed Earth Observing System (EOS) contribution. This effort is the planned centerpiece of the Earth Science and Applications Division of OSSA and is scheduled to be considered for new start status in 1991. As a centerpiece, the EOS concept concatenates all areas of Earth system research and represents the coordinated effort of scientific research for Earth observations in the 1990's and beyond. Because the EOS is the focal point for data analysis in the space Earth sciences, the only way that NASA will not be contributing properly and aggressively to IGBP is in the case that a National decision is made that NASA should no longer be involved in Earth sciences research and analysis.

- It has been the history of the agency that multiple efforts are concurrently underway in a variety of scientific disciplines. Furthermore, it has seldom been the case that a given program was continually funded at the level of desires of the research community. You point out several elements of ongoing efforts within OSSA, each of which are high priority. OSSA makes its best effort to recommend appropriate phasing of major programs so that critical development items are funded at proper times to ensure readiness of payloads and carriers as well as maintaining an ongoing, active research base in support of all efforts. NASA will carry out appropriate support of its IGBP contribution in the face of these pressures by considered, iterated phasing of its efforts as it has always done. The priorities of research demand that a spectrum of opportunities be maintained, and it is NASA's goal to ensure the integrity of such a spectrum.

- TOPEX, NROSS, and EOS are certainly all elements of the Global Change program. More interestingly, they are related in such a way that to assign relative priority becomes meaningless. Certainly EOS is promoted as the centerpiece of the NASA Earth sciences program, but the component parts of EOS, the sensors and the research elements, are all derived through an evolving process of single sensor, single scientific problem to multi-sensor multi-directed scientific enterprise. This means that for example, NROSS and TOPEX as research platforms in and of themselves support not only the oceans space research community, but also the development of oceans sensing/monitoring contributions to the EOS concept as well. EOS cannot exist without the growth through basic research and observation of such parent elements as TOPEX and NROSS (notably the scatterometer). The success of a program like IGBP rests on the existence of a traceable development of research data, analysis, and sensor fabrication which ultimately requires and exploits the opportunities offered by large viewing systems, by integrated data systems, and by multiagency multicommunity sponsored research.

Question 6: Dr. Sally Ride just issued a report recommending that NASA begin a new program "Mission to Earth", which would involve intensive Earth observation and study.

- How would the Ride proposal be linked programmatically to the recommendations of the Earth System Science Committee?

- What consideration has been given to implementation of these proposals?

Answer 6: The recommendation of the Earth System Science Committee (ESSC) constituted the scientific goals and programmatic implementation procedures for NASA, NSF, and NOAA from the members who were strong proxies for the research community at large. The committee's deliberation were exposed to and iterated with many senior level agency and technical liaisons. This research and operations community is the same community to which the "Mission to Planet Earth" concept is directed. Thus, conceptually they are intimately linked. The ESSC recommendations provide the way to start a major Earth observing program, elements of which become the meaning of the concept of "Mission to Planet Earth." Hence, the programmatic implementation of the NASA, NOAA, and NSF elements of ESSC (which are strongly supported in the Office of Space Science and Applications) become the programmatic implementation of this recommendation in Dr. Ride's report. Concepts evolve from Earth system observations to Earth system missions, but the research and activities are identified as the same. NASA's element in ESSC plans, and implicit in "Mission to Planet Earth" is the start of the Earth Observing System project which is not scheduled to request new start status until 1991. But the research has been and continues to move in the direction supporting major, integrated global observation and analysis.

Question 7: The Soviet Union has, as you know, a very robust space program, with a permanently manned space station in orbit today. They have launched some remote sensing platforms as well, and appear to have a virtually unlimited launch capability on a variety of Expendable Launch Vehicles.

- Are any of the present Soviet platforms used in global change research, or to generate data that would be useful in this area?

- Have any efforts been made to coordinate with the Soviet Union either to use data which they have generated, or to place instruments aboard one of their spacecraft?

- Given the present economic, scientific and national security situation, is it feasible to consider using Soviet platforms for scientific instruments?

Answer 7: The recent launch by Proton booster of a large Soviet Earth resources/ocean survey platform is probably intended to support research in disciplines very similar to those contained in the goals of U.S. efforts: hydrology, mapping, geology, agriculture, environmental monitoring, and oceans circulation and perhaps productivity. Because specific details on the sensor complement are unavailable it is not clear what the quality, resolution, transmission rate, or global coverage of the data will be. Certainly, the data will be well-tailored to their research programs in these areas, but the U.S. is currently discussing a cooperative climate research program with the Soviets, but not specifically in support of our global change initiative, nor has there been any discussion relative to Soviet research payloads on U.S. platforms.

Responses to written questions submitted by Senator Pressler.

Global Climate Change

Question: With our national budget deficit pressures increasing year-by-year, what is the urgency for initiating now a national program of "Global Change" -- why should this program assume such a high national priority?

What are the likely consequences and risks if we do not initiate a Global Change program, particularly with respect to ozone depletion and the greenhouse warming effect?

Answer: It is clear that human activities have begun to change the environment on a global scale. The ozone, greenhouse warming, and acid rain issues are just three examples of environmental issues which have recently moved from the purely scientific arena to the political and regulatory arenas. These are not the only, nor will they be the last, environmental issues that will require policy-makers to make difficult decisions that may affect important industries and the economy of the United States. Wise policymaking in this area requires a thorough scientific understanding of the issues. A detailed scientific understanding enables policies to be formulated which protect the environment and are economically least disruptive. If we do not initiate a Global Change program now we will be facing a series of complex and difficult policy options affecting key parts of the American economy such as energy and agriculture in an environment of less than detailed scientific understanding.

Question: I understand that the interagency Committee on Earth Science, chaired by NOAA Administrator Tony Calio, has begun to meet to formulate a national strategy for Global Change.

What fundamental assumptions will direct this Committee's consideration of a strategy for a national Global Change program?

When should this Committee complete its work, and what can we expect as the product of this Committee's work?

Answer: The fundamental organization process for the Committee on Earth Science is in progress and this makes it difficult to state as yet what its fundamental assumptions will be. It is clear that the formation of the Committee indicates an awareness on the part of the Administration that Global Change is an important matter which merits the focused attention of policy makers in this government.

There is considerable difference in the current state of multi-agency agreement between research on understanding the Earth as a system and effects research focused on translating predictions of global change into economic and human health consequences and research on mitigation of future changes. The Earth System Sciences Committee has already given considerable thought to the first need which is a research program to understand the Earth and the changes which are and will take place over the next decades to century. This Committee worked closely with NASA, NOAA, NSF, and the USGS as

well as the Office of Science and Technology Policy in fashioning its recommendations and strategy. NASA certainly expects this to be a key element assumed by the Committee on Earth Sciences.

The work of the Committee on Earth Sciences should not finish with a single product. It will meet an ongoing need for coordination of agency efforts and support of the U.S. Committee on Global Change at the National Academy which will be officially coordinating the U.S. contributions to the International Council of Scientific Unions (ICSU) International Geosphere Biosphere Program (IGBP). The Committee has not as yet specified deliverables for itself and has not yet established an agreed upon schedule.

Question: What are the largest challenges in formulating a sensible national program and in achieving the goals and objectives of the program?

Answer: The greatest challenges are:

(1) to develop the correct institutional framework for the program. The institutional framework has not always been adequate for other large environmental programs;

(2) to design the data handling information system correctly;

(3) to maintain continuity of funding at several agencies, including NASA, NOAA, and NSF, for more than a decade.

(4) for the scientific community to evolve from a mode of performing discipline specific research to one of performing inter-disciplinary and multi-disciplinary research. This may require some changes in the structure of university departments, such as the establishment of divisions of Earth sciences such as that at Harvard University.

(5) to define the breadth of the research program in such a way that it is manageable, and will provide policymakers with the type of information needed for informed decisions.

Question: What institutional framework would allow for an effective, coordinated interagency Global Change program -- one that would optimize the potential for synergism between the involved agencies and also minimize or eliminate unnecessary duplication of effort?

Answer: No new institutional framework is required at this time. The scientific agencies already committed to understanding the Earth's environment, including NASA, NOAA, and NSF, have affirmed their commitment to a Global Change program. The interagency Committee on Earth Science (CES), now chaired by Dr. Dallas Peck will provide the interagency coordination at the highest levels of each of the key scientific agencies required to optimize the potential for synergism between the different agency programs, and will minimize unnecessary duplication of effort. The NAS Global Change panel will provide scientific oversight to the program and will without doubt critique the agencies goals, and implementation strategies. Additionally congressional oversight has always played a

critical role in this area. It is clear that the Global Change program is too important to the American people for the agencies to duplicate effort or to participate in turf battles.

Question: What total federal resource commitment would be required over the next five years to support a Global Change program? Ten years?

What total resource commitment from NASA would be required over the next five years to support a Global Change program? Ten years?

What is an approximate five-year funding profile for NASA's role in Global Change?

Answer: The detailed assessment of the resource requirements for the Federal government and for NASA are still far from being determined. Some of this process is taking place as part of the preparation of the FY 1989 budget. The Earth System Sciences Committee in its overview report presented its assessment of what is required for NASA, NOAA, and NSF to accomplish the Global Change program or at least those parts of it which they could foresee. NASA feels that their assessment is generally accurate although the timing for certain key missions such as Eos has slipped due to the current focus at NASA on getting the space infrastructure working again. To the extent possible, the global change efforts will be accomplished by focusing on-going activities.

Question: To what extent might we anticipate outside participation from private entities, such as laboratories, institutions, and industry in a Global Change program?

Answer: Private industry can certainly be anticipated to participate in the Global Change program, but it is unlikely that such participation will be significantly greater than their current participation in interdisciplinary Earth sciences programs. The governmental resources planned to support Global Change are large compared to projected private sector participation, even given industrial support through those agency channels, so that it is unrealistic to assume that the private sector will be involved at any extent greater than providing a marginal impact. Certainly the public sector will contribute at the local, specific program level to an overall Global Change effort, and industry may well particiate through realization of obtaining a commercial market for data products.

Question: Concurrent with the U.S. Global Change initiative, the International Council of Scientific Unions has formulated the International Geosphere Biosphere Program (IGBP), which is also designed to conduct an inter-disciplinary study of the changing global environment.

How would a U.S. Global Change program be effectively coordinated with an International Geosphere Biosphere Program, and what are the challenges and likely problems in coordinating the two programs?

What duplication is likely to exist in the two initiatives, and how can such duplication be minimized or eliminated?

Answer: The U.S. Global Change program will be scientifically coordinated through the NAS. Duplication of effort will be minimized by the ICSU international scientific steering group, the chairman of which is currently Prof. J. McCarthy of Harvard University, coordinating with the U.S. NAS and CES committees. The planned, not yet approved, use of polar platforms of the space station complex for Earth Observations has strong coordination at both the national and international level. It is this type of coordination which bodes well for effective coordination of any future Global Change program.

Question: Much of the thinking that has gone into a U.S. participation in an International Geosphere Biosphere Program (IGBP) was predicted on use of the Shuttle.

To what degree might a lower annual Shuttle flight rate and greater reliance on expendable launch vehicles (ELVs) affect the timing and extent of the U.S. participation in the IGBP?

The only portion of the thinking and planning for the IGBP that relates at all to the Shuttle is the plans for EOS, the Earth Observing System. Even before the Challenger accident, projected Shuttle performance to polar orbits from Vandenberg Air Force Base was decreasing. This led the mission planners for EOS to request a shift in the assumed launch vehicle for the polar platforms to the Titan IV before January 1986. On-orbit servicing in polar orbit remains an area of uncertainty and current study. If the performance of the Shuttle to polar orbits can be significantly increased the Shuttle could reemerge as the launch vehicle of choice for polar platform initial deployment and servicing. Without such an effort, ELV launch will be used without compromising the payload of the polar platforms. Servicing would be the main area of significant impact to the IGBP program resulting from the Shuttle situation.

On-orbit servicing has been part of the baseline planning for EOS as a means to achieve fifteen year life for the polar platforms and Earth observing payloads. The key for IGBP is sustained data acquisition over a long time period. On-orbit servicing is only one means to that end. The current system of using expendable spacecraft and instruments can achieve the same result, particularly if five year orbital lifetimes can be routinely achieved for both platforms and instruments. On-orbit servicing scenarios using robotics and ELV launches are currently under study. At present it is unclear as to which approach to obtaining long life sustained observations will prove technologically or economically advantageous.

Question: Are there lessons that have been learned from conducting or participating in other large international science programs that might benefit the U.S. in terms of setting up an International Geosphere-Biosphere Program itself and in establishing the national and international organizations?

Answer: In 1979 the World Meteorological Organization (WMO) and the International Council of Scientific Unions (ICSU), following the successful model of the Global Atmospheric Research Program (GARP), jointly established the World Climate Research Program (WCRP). The main objectives of WCRP are to determine to what extent climate can be predicted and the extent of man's influence on climate.

The first informal international planning meeting on the WCRP was held in Geneva in 1986 to review the climate research plans of countries and multi-national organizations which planned to participate in the implementation of the program. The U.S. was a major participant in this meeting. The delegations agreed to an overall research strategy for the WCRP, formulated in terms of scientific objectives or "streams" focusing on establishing the physical basis for climate predictions on time scales of one to two months, over periods of up to several years, and ultimately, over several decades. The spectrum of current and planned WCRP projects addressing these objectives (viz, ISCCP, TOGA, WOCE, GEWEX) involve important contributions by NASA.

It was recognized that the new International Geosphere Biosphere Program (IGBP) initiative of ICSU would encompass a wide field of environmental problems, including marine and atmospheric chemistry and the study of bio-geochemical cycles in the earth environment in general. A great variety of chemical species and processes will be studied within the oceanic, atmospheric and land surface chemistry or bio-chemistry components of the IGBP, but only a limited number would require the type of internationally coordinated field studies or global modeling projects promoted by the WCRP. It was concluded that in the future, there might be a need to merge some global aspects of the study of bio-geochemical cycles considered in the IGBP with the objectives of the WCRP.

Conversely, the WCRP should take appropriate initiatives to ensure that, as well as other more detailed scientific perspectives, the global outlook characterizing climate processes should be incorporated, from inception, in the definition of IGBP plans.

Question: Will the Federal agencies rely solely on the National Academy of Sciences Committee on Global Change for guidance and expert advice as to how to steer their respective contributions to the Global Change program? If not, then through what other channels?

Answer: The NAS Global Change Committee will clearly serve as a key scientific advisory panel. However, NASA will continue to use its existing advisory panels, such as the NASA Advisory Council, and the Earth System Science Committee (ESSC), to advise NASA on its programs. This advice will be shared with the NAS committee and no conflict should arise. Indeed many members of the NAS committee are members of the NASA ESSC and were members of the earlier NASA Global Habitability panels.

Question: One of the keys to the success of a Global Change effort is the proper management of the data and the establishment of adequate information systems that have an evolutionary capability.

Which agency or agencies should take the lead in managing the data and in handling the information systems?

Answer: The key operating principle here is that if the Global Change data are to be properly handled and preserved, each data set should be managed by a community with specific interest in its use. This implies a distributed data handling environment with interoperable system elements. Each participating agency (NASA, NSF, NOAA, USGS, etc.) supports research communities with particular interests, and should retain responsibility for servicing and coordinating the data handling and preservation needs within these groups. NASA is planning to assume a lead role in the processing and distribution of satellite data from research payloads. Coordination at the interagency level should take place through the Committee on Earth Sciences, recently chartered by the President's Office of Science and Technology Policy, and coordinated with the U.S. Committee for Global Change of the National Academy of Sciences. The goal of the interagency effort should be to establish common terminology, data exchange standards, data retention guidelines, interoperable catalogs, and standard network protocols.

Question: What are the national security implications and considerations in establishing a Global Change program and in U.S. participation in an International Geosphere Biosphere Program.

To what extent is the Department of Defense or any other national security agency expected to participate in a Global Change program?

Answer: The Department of Defense and intelligence communities would be interested in climate changes that would affect the economic base of the U.S. or other countries or that might influence the operational factors for defense systems. In addition, remote sensing systems that provide spatial and temporal data on atmospheric, oceanographic or land processes may also contain data of potential value in the defense intelligence areas. This would not be a new factor with a Global Change program but has been an ongoing DoD consideration for several decades. In particular, other nations are already expanding their capabilities for civil programs to observe the Earth from space.

The Department of Defense is a member of the OSTP Committee on Earth Sciences and thus will have the opportunity to keep informed on the civil Earth Sciences programs and plans and on any committee recommendations for national policy changes. DoD participation in a Global Change program has not been identified.

Question: Will U.S. plans for a Global Change program be embodied in an official statement of national policy, and how will a determination be made as to whether sufficient budgetary suport has been committed to the program?

Answer: There are numerous Executive Branch policy statements establishing this research as an area of national importance, including the President's 1987 State of the Union Address. Principal expressions of this support are the budget justifications of Federal agencies and annual testimony in support of these budget requests.

The Global Change program is a long-term research enterprise that, as it accumulates knowledge, will be identifying additional questions and areas of emphasis. Government-wide planning for the Global Change program needs several budget planning cycles and interagency reviews prior to any formal policy governing a specific approach and overall cooperation with the science community, to identify a realistic and responsible national Global Change program, especially in the current constrained fiscal environment. The knowledge gained from this initial planning process will eventually permit the development of a scientifically sound and fiscally realistic national policy. Relative to the other research areas of national significance, it appears that Global Change program resources, for the most part, are commensurate with agency needs over the current planning period.

Question: By what standards should a U.S. Global Change program be measured, and what should be the measure of "success" in this program?

For what scientific reasons might it be necessary to discontinue a Global Change program after it is initiated, or, put another way, is there a quantitative or qualitative threshhold that such a program should meet in order to justify its continuation?

Answer: It is difficult to set firm quantitative goals for broad programs of research even when they are focused on a specific goal. Incremental progress is difficult to judge in the short run.

With IGBP, the Congress should look first for a general series of significant improvements in our understanding of the Earth. These improvements will at first occur simply because Earth scientists from a variety of disciplines begin to work together and become stimulated to a fresh examination of existing observations. A good example of this is the vegetation index research using the AVHRR instrument on the NOAA satellites and its extension to SMMR observations from Nimbus 7. After there has been time for new research efforts to be carried out and for the data from them to be studied, there should be significant improvements in our understanding of broad connections within the Earth system and a consequent increase in our ability to do certain types of prediction.

Over the last decade the predictions of global ozone depletion have varied widely and over a range where the public policy implications differ significantly. Now there are observations of an ozone hole but the implications of these observations are completely unclear. If IGBP is ultimately a success, this type of scientific uncertainty should become far less frequent and an international consensus on the course of future changes should become easier to establish. Then the policy maker will have a larger foundation of solid scientific information from which to work.

There are no scientific reasons why the Global Change program should be stopped that one can anticipate.

Question: According to your statement, NASA's Earth Observing System (EOS) is the center piece of NASA's activities with respect to understanding global change. Furthermore, your statement indicates that the EOS will make use of the polar-orbiting platforms in NASA's space station program. Yet, because the Shuttle launch complex at Vandenberg Air Force Base has been "mothballed" indefinitely, this makes the manned "serviceability" feature of these platforms highly questionable.

What with the future of Vandenberg for Shuttle launches in such great doubt, how is this affecting the planning for the polar platforms that are central to the EOS?

If Vandenberg Air Force Base does not support Shuttle launches, how will this affect the EOS and the Global Change program, and what can be done to compensate for the absence of this capability?

Answer: A detailed discussion of the Shuttle Flight rates and ELV usage is contained in a previous question. If approved, long term data acquisition by EOS can be accomplished without use of the Shuttle. Titan IV launches will be required for initial platform launches for EOS if there is not high-performance Shuttle capability at Vandenberg. Unless the Shuttle performance from Vandenberg becomes comparable to that of Titan IV there will be no change in this requirement for initial launches. The total lack of Shuttle capability for launches to polar orbits would require either the development of ELV based on-orbit servicing or the use of long lived expendable approaches to the EOS polar platforms and payloads. It remains unclear which approach would be the more advantageous for overall U.S. space policy.

Question: It is widely understood that satellite land remote sensing will play an important role in a Global Change program.

Just how critical will satellite land remote sensing data be to the success of such a program?

How important is a U.S. satellite land remote sensing capability to a Global Change program, and to what extent would a U.S. commercial land remote sensing capability be able to meet these national requirements?

To what extent should the U.S. be expected to rely on satellite land remote sensing data from foreign satellite systems -- would this be a practical option if there were no U.S. Landsat system?

Answer: The National Research Council has recommended five major problem areas for inclusion in a Global Change program that are currently under review. A comprehensive suite of satellite observations of land surface properties and processes could be focused on each of these problem areas. Examples of applications of land remote sensing data in each area are: 1) the recovery of the past history of environmental change - remotely sensed observations of geomorphology and surface mineral composition could be used to reconstruct the Earth's past climatic history and thus discern human from natural influences on present climatic fluctuations; 2) changes

in the current physical environment - satellite measurements of the albedo of the land surface, including regions covered by snow and ice, could be used to understand the Earth's energy balance and the effects of changes in the land surface on climate; 3) global changes in the biosphere - satellite inventories of global vegetation cover and productivity, combined with regular monitoring of their changes, could be used to assess the Earth's metabolic capacity and to provide vital, up to date information on the productivity of agricultural lands, rangelands, and forests; 4) global biogeochemical cycles - remotely sensed observations of volcanic activity, vegetation, biochemical composition, and dynamical changes in the structure, composition, and function of terrestrial ecosystems could be a component in the characterizing, monitoring, and predicting changes in the major biogeochemical cycles of the Earth; 5) the global hydrologic cycle - satellite derived measures of the land surface reservoirs and fluxes of water could be used for developing an understanding of the couplings between the components of the Earth system and the rates of fluxes among them.

Satellite remote sensing of the land is the sole means of obtaining and integrating information of the scale and detail required, in the timely manner required, by a Global Change program. Measurements spanning the electromagnetic spectrum and at a variety of temporal and spatial scales are used for understanding changes on the Earth's land surface; their effects on global climate, energy balance, and biogeochemical cycles; and their impact on atmospheric and oceanic processes. Examples of the capabilities are: radar observations of snow and ice properties and land surface roughness; passive microwave observations for estimation of soil moisture; thermal infrared observations of surface temperature and emissivity; and visible and near-infrared observations of land cover, volcanic activity, vegetation productivity, and surface albedo. Frequent, global coverage would monitor changes on the time scale of days to weeks. Less frequent, high spectral and spatial resolution observations of local to regional coverage would identify surface materials and obtain detailed information about land surface processes.

Existing U.S. satellite capabilities including AVHRR, GOES, Nimbus and the commercial Landsat will satisfy many but not all of the observational requirements of a Global Change program. This full complement of satellites will provide the continuous record of recent changes on the Earth's surface that will be absolutely necessary for assessing global changes over the time frame of decades. The land remote sensing research community would like to see that continuity is maintained in these existing data sets. Other requirements will call for data from experimental research sensors which do not presently exist in satellite form (although aircraft- or shuttle-based prototypes may exist) and may not be commercially viable by the 1990's. Examples of such experimental sensors planned for land remote sensing include the High Resolution Imaging Spectrometer (HIRIS), the Synthetic Aperture Radar (SAR), and, if approved, the High resolution Multifrequency Microwave Radiometer (HMMR) for the Earth Observing System. Of course, all of these requirements will have to compete with all NASA and other agency program priorities.

The U.S. (from individual researchers to federal agencies) already makes use of foreign commercial satellite data through the French SPOT satellite. NASA has reached an agreement with the European Space Agency to receive and utilize data for research purposes from the European SAR satellite scheduled for launch in 1990, and is negotiating with Japan for a similar arrangement with the launch in 1992 of their satellite carrying a SAR and an optical sensor. In order to achieve the level of routine observation and interpretation required to monitor global change, the currently conceived program requires more satellite coverage than one nation's space budget could provide. Thus, plans for a U.S. Global Change program are being developed in concert with those of Europe, Japan, Australia, and Canada for their satellite facilities and space platforms.

Question: Similarly, how important would be capabilities offered by the EROS Data Center be to a Global Change program, and how might the functions of this facility be expanded to support a Global Change program?

Answer: Data handling is an important component of a Global Change program. Several agencies and data handling groups are currently meeting to plan a coordinated approach. The capabilities of the EROS Data Center (EDC) in cataloging and making available satellite and aircraft data to researchers, and the current agreement with NOAA that the EDC serve as archive of Landsat data, indicate the type of function that the EDC might perform in support of a U.S. Global Change program. The future of EDC is currently the subject of a formal review by the U.S. Geological Survey. NASA is involved in this review.

Question: Is the U.S. scientific academic infrastructure of high schools and colleges sufficient to support such a national Global Change initiative, not only with research but also with a steady supply of qualified scientists?

If not, what is being done to address this deficiency?

Do human resource problems exist on an international scale?

Answer: I believe that the U.S. scientific academic infrastructure is presently adequate to support a Global Change initiative. This is because there are already strong disciplinary programs in oceanographic and atmospheric research and in research on land processes including the biological component. However, there will be a growing need for scientists that can perform interdisciplinary research and this is an area where additional academic focus is needed.

Our international colleagues have not made us aware of any human resource problems.

Question: What, if any, technologies need to be developed to adequately address the issues that are central to Global Change, and what level of federal investment would be required to develop these technologies?

Similarly, how great an investment in national facilities must be made to support a Global Change initiative?

Answer: The most significant technology needing enhancement to support a Global Change initiative is the development of high speed, long term, reliable data storage techniques and the development of high speed analysis capabilities for many channel optical and microwave imaging data. This is basically a type-of-media issue: how does one get lists of data onto a (say) optical medium and off the medium, and how long can the integrity of the data be preserved on that medium. Such techniques are essential to support the Earth Observing System which, if approved, could be a part of Global Change. However, in these areas, the private sector commercially inspired efforts are adequate to meet the research goal in a timely manner. Additionally, further remote sensing technique development is necessary in a number of research areas. Various emerging technologies need to be implemented to ensure success, and in particular, to support an effort of developing spaceflight capable hardware through some rational learning process,in-situ technique measurements could be improved. There are a number of high speed, high accuracy detector and instrument developments underway, and we expect, if resources are available, that these will be ready by the mid 1990's. Of fundamental importance to the success of Global Change is not only to obtain resources, but also to gain cooperation between all elements of the government, various agencies, the research community, and the private sector.

It is far more difficult to assign appropriate costs needed for National facilities due to the variety of needs. The scope of the Global Change effort runs both from the need for large, capable data processing facilities to the many Ecological Preserves created for study of changes in particular biomes necessary for full understanding and isolation of change processes. Global Change is a distributed scientific enterprise permeating potentially all universities and government research centers. The issue is not so much to create new facilities as it is to enrich and focus the facilities that are already in place.

Senator GORE. Thank you very much. I understand that you have a film with you that has just about two or three minutes of a model that NASA prepared. Oh, you did not bring it. I thought that was it there.

Oh, I am sorry. We have the film.

That is why you looked puzzled.

Dr. FISK. I would be very pleased to see the film.

Senator GORE. It is from NASA.

Dr. FISK. I am sure it is an excellent film.

Senator GORE. It is prepared on the basis of a model of climate change worked out in NASA by Jim Hansen, among others, at the Goddard Institute.

What he and his colleagues at NASA have done is to prepare an interactive computer model of what the effect of the warming will be in different latitudes, in different parts of the world.

And there are other potential models, of course. This is the most comprehensive one that has been built so far. But just a word of explanation beforehand. As I remember this film, the different colors used represent different temperatures.

Red being the hottest. Blue being the coldest, as I remember. And it is almost like time-lapse photography, in that it shows the change in temperature and climate over a period of time, according to this NASA model.

[Picture shown.]

Senator GORE. Now, it starts in the present time, and it runs over, I believe, several decades. But the yellow, orange, and red areas represent the appearance of warmer temperatures. And the changes begin to pick up speed a few decades out, particularly in the higher latitudes.

Because of the phenomena mentioned earlier, the warming takes place more rapidly in the higher latitudes. There are summer and winter fluctuations as well, depicted in the model.

But as we move into the next century, you can see in the southeast of the United States, where I live—And after only a few decades, the summer peaks begin to get very much warmer than now.

And when you compare these temperatures to the ones at the beginning, it demonstrates graphically the kinds of changes predicted by this model. And by now we have started to see the loss of some cold fluctuations that were in the earlier decades.

And this does not cover that many decades. We are in the year 2012 now. As you can see in the United States it is pretty hot, according to this model. What year is this now?

Dr. CORELL. 2020.

Senator GORE. 2020. The degree fluctuations are on that scale at the bottom. I can not read them.

But the point of the film is that, these are the same predictions which many read about a year or so ago predicting an increase in the number of 100 degree days in different cities around the United States.

So as you can see by the year 2030 the model shows a very dramatic change in the temperature around the world, in line with the earlier comments. The number of 100 degree days in Memphis, Tennessee would be increased rather dramatically.

Well, I think that is enough to make the point. The NASA representatives at a climate change conference, which I attended last year, showed that film. And I thought it made it easier to understand some of the projected impacts.

In any event, thank you. Our last witness is Dr. J. Michael Hall, who is Director of the Office of Climate and Atmospheric Research at NOAA, the National Oceanic and Atmospheric Administration.

Mr. Hall, welcome. I appreciate your presence here.

STATEMENT OF J. MICHAEL HALL, DIRECTOR, OFFICE OF CLIMATIC AND ATMOSPHERIC RESEARCH, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Mr. HALL. Thank you, Mr. Chairman. I am also delighted to be here and be part of a hearing on such an important subject.

Senator GORE. Can you move that mike a little closer?

Mr. HALL. Certainly. I plan to close this morning by summarizing the NOAA perspective on problems of global change and our approach to these problems.

But, with your permission, I would begin by picking up on something you said earlier about what can be found in the historical record, that is in human history, that might illuminate the kind of problems we are looking at and, more importantly, might help determine how we should approach those problems.

The record of climate change, through use of proxy data and other techniques, extends far back in time. I'll start with this figure to show you that it is possible using various sources of information, to look back at least several hundred thousand years and examine the major ice age excursions in climate. Similarly, we can look back over the last 25,000 or 30,000 years to examine the last major ice age in considerable detail and so on.

What I want to do is expand the last 1,000 years of the record—this is the temperature curve for that period—and talk about some remarkable things that have taken place in recent historical times, a period I think we can all understand and to some extent relate to.

I'll focus on the portion of this curve from about 900 to 1600, so that you can see it in a little better detail. We will examine two relatively stable, but quite different periods of climate in northern Europe and England, that lasted for 200 or 300 years each.

Each of these periods had worldwide climate consequences but I will focus on this one region in particular. In the period of around 1000 to 1200 or 1300, approximately, what was known as a little climate optimum occurred, characterized by relatively stable and benign conditions. It lasted for a few hundred years and coincided with a period of relative enlightenment and progress in Europe, the period of cathedral-buildings, for example.

Senator GORE. Now, that graph is going from right to left instead of——

Mr. HALL. I am sorry, yes, it is backward from a normal figure.

Senator GORE. Okay.

Mr. HALL. The second relatively stable period in this region existed around 1400 through 1700. Again, different portions of the

world experienced these conditions for different lengths of time. This period has become known as the little ice age because conditions cooled worldwide.

In northern Europe, during the period of change from optimum to cool, the average weather conditions went from dry and mild winters to an extended period of very wet severe winters.

One of the things I want to point out is that, during the period of the climate optimum, Greenland, the world's largest island.

Senator GORE. Before you get to the effects on that society, the two different climate periods are associated with a fluctuation of 1 degree. Is that correct?

Mr. HALL. Yes. That is an important point. The difference between these two periods is approximately a degree to a degree and a half, in global scale temperature averages. Those are degrees Celsius, by the way. The magnitude of change depends on which part of the world you look at. But it is possible to recognize both of these periods worldwide, particularly the little ice age.

Senator GORE. Now, just to set the context of what you are saying here. The thrust of your testimony is not that these changes had anything to do with anthropogenic effects.

There are two kinds of climate changes. There are the natural fluctuations that occur due to forces that we do not fully understand. And there are the new unprecedented changes that are coming about because of the effects of human civilization, industrial civilization.

But what you are saying is that, when you analyze the smaller climate changes that are part of the natural fluctuation in climate, you can see in human history some rather dramatic social consequences from changes on this scale.

So, please go ahead.

Mr. HALL. Let's examine the kind of social changes you see, and contrast those social conditions (and the magnitude of global change it took to bring them about) with the sort of changes that have been speculated upon this morning, global warmings of several degrees Celsius.

For examle, during the little optimum England experienced relatively benign conditions and wine vineyards were fairly widespread throughout Southern England. In fact, the English became somewhat competitive with the French in the wine business during that time.

Greenland during this period was also somewhat inviting as a place to live. It remained largely covered by icecap, but the margins of Greenland, particularly in the south and the west, were widely colonized by northern European societies.

An agricultural-based society fluorished there during the little optimum. And yet by the time of 1500 to 1600, those colonies had all disappeared. Their demise resulted from a combination of climate change induced by the global cooling of the little ice age, and their inability to foresee and respond flexibly to that change.

The second point worthy of note here, also supported by historical records, is that the transition from relatively benign conditions to relatively harsh conditions occurred very abruptly in many regions of the world.

In England, for example, rather than taking 200 or 300 years, as this curve might imply, the transition happened fairly abruptly. It occupied certainly no more than 50 years, some authors think it took as little as one decade to go from relatively wild, storm-free winters to the more severe conditions of the little ice age.

Some authors have written about a climate shock that occurred in England about 1300. One of the reasons this particular curve does not show such an abrupt transition, by the way, is because proxy records typically have a way of smoothing curves, making them vary slowly.

Historical records thus contain information about changes in the climate system, information that we must exploit if we are to understand how it changes.

The way in which a system goes from a relatively stable mean state, in this case the little optimum, to a different, relatively stable mean state of about a degree and a half cooler, is very poorly known. But the transitions themselves are worthy of concerted study.

Senator GORE. In other words, the change can be abrupt. And you can move, to put it another way, from one kind of equilibrium to another, just as when a gyroscope in balance is knocked out of balance, it can happen suddenly.

And a global weather system can operate smoothly at one average temperature, but when that temperature changes, the way it operates changes rather rapidly and it searches for a new kind of equilibrium.

Mr. HALL. Exactly. Something called a state transition can take place. And this is a good point for me to reiterate the message from my colleagues this morning.

Earth system science promises to view the system in a complete way, and provide, for the first time, a means to approach the climate problem with a systematic, scientifically sound global view.

One consideration then in designing a national or an international program is to look at the historical record. This next figure shows probably the best data on changes over the last 100 years, in this case sea surface temperatures, together with a schematic depiction of potential future changes. With such data, we can ask, has there been a warming or is a warming, now underway? Secondly, we are compelled to look into the future with the best possible science, the best models, and to try to determine what sort of effects, what kind of an envelope of possible change we are going to have to live with in the coming decade.

Essentially, that motive is what determines the outward appearance of our program in NOAA . . .

Senator GORE. Could you put that last figure back up again? You have three possibilities on the right hand side of the graph. Is that what you are saying?

Mr. HALL. Well, just an array of possibilities. There is a remote possibility of a runaway greenhouse scenario from very strong feedback mechanisms. I do not wish to speculate on that. But that possibility is depicted here as one possible outcome. You may also remember a decade or so ago there was concern that atmospheric particulates, aerosols, were going to result in cooling. This figure is just a cartoon rendering of the fact that we do indeed look forward

to a very heightened envelope of uncertainty about where we are going.

Senator GORE. All right. Thank you.

Mr. HALL. If I might return to my seat and summarize the material in the next figure.

There are four elements in what NOAA is proposing to do, and they are designed to focus this broad array of national efforts, described to you briefly in our testimony, and bring them to bear in providing scientific information for use by decision-makers.

The first of these program elements is long-term measurement of changing global conditions. I note that a very strong national effort is necessary in this regard, and we are in the process of deciding which agencies will undertake which parts of that effort.

Secondly, the documentation of past change, and the assessment of present trends, is a vital part of a balanced program. That is to say, looking back in time is as important as looking forward, we have to do both in order to be successful.

Thirdly, we must continue the development of predictive models. But I think you have implied correctly that we have increasingly to use predictive models to provide information to those who make decisions, those who formulate public policy.

I would also note that because we are talking about prediction on time scales of several decades or more, validation, in the normal sense, making a prediction and seeing if it comes true, is not going to be adequate. That is where the historical record comes in.

If we can replicate past change, if we can duplicate transitions of state in the climate system, one of which we just looked at, then we will have increased confidence in our models.

Finally, we need to pursue a focused program of research. In the case of NOAA, that research program is narrow and has two motives. One is to improve predictive models. Perhaps the best ongoing example is the work we and other agencies are doing in the TOGA program to predict year-to-year variations.

The second motive of our research is to distinguish natural from man-made change. There are a number of such efforts going on, but the one that NOAA is the most active in, together with NASA, NSF and others, is the work on the chemical interactions of radiative gases in the atmosphere. This research is designed to determine to what extent changes in ozone, for example, can be attributed to human activity versus the extent to which they might be a result of natural phenomena.

We feel, Mr. Chairman, that if we mount a balanced attack on these four elements, if we in NOAA focus our attention on pulling the many agency efforts together into a working scientific information service, we can support U.S. decisionmakers well into the next century.

Thank you, Mr. Chairman.

[The statement follows:]

STATEMENT OF J. MICHAEL HALL, DIRECTOR, OFFICE OF CLIMATIC AND ATMOSPHERIC RESEARCH, OFFICE OF OCEANIC AND ATMOSPHERIC RESEARCH, NOAA

INTRODUCTION

My name is J. Michael Hall, Director of NOAA's Office of Climatic and Atmospheric Research.

THE PROBLEM

You have heard testimony today that mankind is no longer a passive participant in the global environment. Human activity has already reached the point where it is affecting the earth system, in ways we can just begin to perceive but do not fully understand. You have also heard about national and international movement toward programs to measure, predict and respond to global change. Consideration of the effects of global change on human activities is inevitably making us more aware of the large natural variability in the global system—the degree to which our global environment fluctuates through normal, natural processes—and the problem of discerning between natural and man-made change.

The combined effects of natural and man-made change can have profound economic and social implications for the future. Possible depletion of the earth's ozone layer, the potential for greenhouse warming, and large scale and persistent regional drought are but a few examples of the problems we face. The nations of the world must be prepared to understand and to address these serious issues. The nature and quality of the decision process can be improved if we understand what supporting information is needed and whether it can be made available on a timely basis. Today we have far too little scientific information to address these problems effectively; but you heard earlier from NASA and NSF that we have an unprecedented opportunity to achieve the necessary insights.

I will confine my remarks this morning to the earth's climate system (an important part of the earth system), for two reasons: (1) the NOAA responsibility lies particularly in the climate portion of the problem, and (2) the slowly changing behavior of the atmosphere is the avenue through which we experience many of the more subtle changes in the larger earth system. This discussion will focus on the climate system, and the way it changes.

The effects of climate variability on human activities, on the stability of societal institutions, and even on the earth's ecosystems and their ability to sustain life, have always been exceedingly difficult to quantify. Climate patterns are deeply ingrained in virtually all human activities, and we are often unaware of the extent to which societies are built around known climate variability, and of their continuing vulnerability to unanticipated climate change.

The effects of climate change on human activities can be viewed in two ways; (1) year-to-year (interannual) variability in climate, which has profound economic and strategic implications as we adjust (or fail to adjust) to real or projected change, and (2) long-term (interdecadal or longer) changes, which have imposed limits on human activities throughout history, affecting even the basic stability of social structures. The second of these effects goes beyond anything that can be readily quantified.

When we speak of projected changes in the earth system of a few degrees Celsius in average global conditions, it is difficult to describe in simple human terms what such a change might mean. Yet, we have experienced changes of this magnitude in recent historical times and can readily illustrate the kind of environmental conditions accompanying a global change of even one or two degrees. In the region of England and northern Europe approximately 1,000 years ago, for a period of a few centuries, societies enjoyed a modest climate 'optimum,' or relatively benign period. Well-established historical records indicate that the region enjoyed relatively warm and stable temperatures and an unusually productive agricultural environment. Wine vineyards were widespread in England, for example, and Greenland was inviting enough to be widely colonized. Greenland, in fact, derived its name from its ability to support an extensive vegetation cover, and a substantial agriculturally-based society flourished there. Remarkably, only a few centuries later this same region was suffering what has become known as the Little Ice Age, when average conditions were notably colder than they are today. The polar ice cap grew to cover all of Greenland, as it does today, and European colonies completely disappeared. England experienced harsh winters and unusually cold summers; the Thames was often frozen over. The global scale temperatures during these two contrasting periods differed by perhaps 1°C to 2°C. Even more remarkably, the transition between this minor climate optimum of the last millennium and the Little Ice Age of the 13th through 17th centuries occurred very abruptly. The transition from relatively opti-

mal to harsh conditions in some regions occupied a few decades or less. There is no certain explanation as to why this condition occurred.

Changes in the earth's climate system sufficient to cause major dislocations in optimal agricultural conditions have thus occurred in recent human history. We have a good idea of the magnitude of these changes and the relatively short time over which they occurred. Such examples emphasize the fact that the societal impacts we are contemplating from future change are well beyond simple estimation or quantification in economic terms. The extinction of an agricultural society in Greenland is beyond quantifiable significance to the people who lived there. The Vatican archives contain comments by Pope Alexander VI, written in 1492, expressing concern that ". . . the church of Garda is situated at the ends of the Earth in Greenland . . . shipping to that country is very infrequent because of the extensive freezing of the waters—no ship having put into shore . . . for 80 years . . . no bishop or priest . . . in residence for 80 years. . . ."

A second example illustrates the effects of year-to-year variability in climate and offers at least a hint of how climate prediction (if reliable) can be put to practical use.

In January 1983 Congress initiated a new program called Payment-in-Kind for holding U.S. agricultural land out of production (through subsidies) in order to avoid excessive crop surpluses. The Federal government assumed that the normal seasonal changes in our agricultural environment for 1983 would largely resemble those of other years. We now know that 1982 and 1983 were not at all like other years, and that the summer of 1983, in particular, would turn out to be a period of devastating heat wave and drought for farmers in the American Midwest. Quoting from the MIT *Technology Review* (Jan. 6, 1985), "Ray Daniel of Chase Econometrics notes that if planners had known that drought would reduce corn farmers' production by a billion bushels in 1983, they could have saved $20 billion on the payment-in-kind program. . . ." This quotation suggests that advance climate information and the willingness to use it strategically may have been worth billions of dollars that year. It is the Administration's position that the scientific understanding of the global climate system is far too inadequate at this point to suggest that this knowledge can be used in policy decision making. Might we have known of an impending climate fluctuation?

In 1982–83 one of the most significant interannual climate fluctuations of the last century took place. This worldwide climate phenomenon is known as El Nino and the Southern Oscillation (ENSO), for its oceanic and atmospheric components. This phenomenon has been the subject of intensive international study for the last decade, and a great deal is now known about how it works to affect a global change in the earth's climate that lasts from one to two years. The direct consequences of these changes have been highlighted by the well-documented changes in the availability of fishery resources off the Pacific Coast of South and Central America during the El Nino periods. Figure 1 illustrates that the tropical Pacific Ocean, where this particular climate perturbation originates, was experiencing a very intense warming by December 1982.

From these and other data it is now possible for scientists to recognize the presence of such an event and to anticipate that there will be worldwide consequences through altered patterns of prevailing weather conditions. It is not yet possible to demonstrate that the worldwide (ENSO) climate fluctuation that had established itself by late 1982 was a direct cause of the subsequent summer drought in the central United States. The casual links, if any, between the two are poorly known and are still subject to intensive investigation. The problem of unravelling the connections between global scale climate variations and regional effects such as the summer drought of 1983 is of great practical relevance. A reliable prediction six to eight months in advance, had it been available, might have affected a multi-billion dollar decision over one of the most important sectors of our national economy. While we are a long way from making such a prediction, we know how to study many of the remaining problems in producing information of this type.

The theme that climate information has major strategic value in the subtle workings of a society, as well as the potential for severe dislocations in worldwide social patterns is well illustrated by a final example.

Over 4,000 years ago man formed one of the earliest civilizations along the banks of the Nile, where the climate system is dominated by a single factor—the river. The Nile is a classical example of a tropical river regime for which the annual late summer flood is the principal factor in agriculture. In *The Discoverers,* Daniel Boorstin writes that the Egyptians of that period were able to observe the motions of the sun and stars and to formulate an understanding of how their simple climate

system changed throughout the year. They could predict the coming peak river flow and take advantage of its flooding for agricultural purposes.

The Egyptians built an enduring civilization around the annual cycle of the Nile. This civilization was predicated on a climate prediction, the assumption that the annual cycle would perpetuate itself indefinitely. Basically, it was a good gamble; that civilization endured for three thousand years. On the other hand, the Egyptians found themselves vulnerable to year-to-year variations in the discharge of the Nile, variations that denied them the annual replenishment of their agricultural base. They also had no ability to foresee long-term changes in Nile River discharge and to protect themselves from associated climate effects. A typical record for one century of Nile River flow is shown here. It is most striking in its enormous year-to-year variability and in the fact that the annual discharge abruptly decreased by over 40 percent. There is historical evidence that such changes occurred periodically during the height of Egyptian civilization and that Egyptian society suffered frequent, often serious consequences.

Not a lot has changed in the preparation and use of climate predictions since the Egyptian experience beginning 4,000 years ago. Today we have a sophisticated and complex society that is very finely tuned to the annual cycle and associated regional patterns of climate and yet, perplexingly, we remain largely passive victims of climate change on most other time scales. Some notable exceptions to this condition do exist, but they are few. (Modern agriculture, for example, is adaptive to a range of changes that can occur on decadal time scales.)

There are several important circumstances which have changed since the time of the ancient Egyptians: (1) our grasp of the basic way in which the climate system can be studied, as a single global system, (2) a technological capability which, for the first time, makes it possible to examine the climate system globally in sufficient detail, and (3) the availability of computers and numerical models that may ultimately enable us to project climate change on scales of a few months to many decades in the future.

You have heard testimony that scientists throughout the world have devised a new and effective way to address problems of climate and global change by viewing the earth as a single system, in which climate is one important element. The Global Geosciences program of the National Science Foundation is strong evidence that scientists are poised for a broad attack on the research problems inherent in this undertaking. The question now at hand is how this broad national and international attack on earth system science, and the inherent global climate system, will be focused and applied to the pressing human problems we now encounter. The examples cited above, and today's testimony, suggest that climate information is of profound value, that policy decisions can readily be tied to scientific information, when it is available and of sufficient quality, and that the prospects are good for major advances in the necessary understanding. If there is a single key to the application of tomorrow's climate information to practical problems, that key is prediction.

THE NOAA ROLE

For more than a year now, NOAA has been considering in detail the problem of global change, in order to determine how it affects the conduct of our programs. Years of work on problems of climate change, in successful ongoing efforts, provide a strong base around which we are building a program responsive to tomorrow's needs. We have considered the plans of other agencies and the emerging international scientific framework, and we have examined the societal problems and strategic decisions to which earth system science knowledge must be applied. Of course NOAA understands that fiscal realities require that we maintain a perspective based on highest priority mission responsibilities, while bringing to the problem those unique capabilities we have developed as an agency.

NOAA's contribution to global change has and will continue to be focused on climate prediction related to changing conditions in the earth system, an integrated "climate and global change" activity. We have projected NOAA's climate activities into the mid to late 1990s in the light of emerging scientific insight and the problems of public policy presented by issues such as greenhouse effects, ozone depletion, or persistent regional droughts. We are developing plans for moving NOAA toward that ten-year vision. Our long-term goal is the achievement of reliable assessments and quantitative predictions of changing global climate. The focus will be on climate changes of critical relevance to our society, those which occur over interannual (year-to-year) and interdecadal (a few decades) time periods. We are striving to mold present efforts into a program in earty system science that is uniquely tailored to

NOAA but fully integrated into and supportive of the broader U.S. interagency and international effort.

The program has four parallel elements which we believe together constitute an effective attack on the problem of global climate change. In all cases, the NOAA effort builds on strong existing programs that, for years, have been adding important insight to our perspectives on global change. Each element requires and will receive a concerted and purposeful approach, keyed to the information requirements presented by today's practical problems.

A. NOAA's long-term measurements of changing conditions supports earth system science in the context of the international effort. We now have in place several important monitoring activities. These include our global atmospheric CO_2 network, the large-scale ocean monitoring being done in El Nino studies, and operational satellite products such as global sea surface temperature. The most complete single observing system in earth system science today is arguably the atmospheric observing system that supports weather prediction—no single national entity in the world does more to maintain this end-to-end system than NOAA. Other activities within this element of the program include space based observations from operational satellites, land surface conditions, vegetative cover, and sea-ice conditions relevant to the problem of climate change. One class of observations that will receive particular attention is the global observational network for studying the oceanic role in long-term climate change. We have learned enough in recent years to know that the ocean's role is critical to realistic projections of change from increases in radiative gases in the atmosphere. One of the principal uncertainties in determining how increased CO_2 might affect the climate system, for example, lies with the little know oceanic processes that remove atmospheric CO_2.

A second substantial dimension of the long-term monitoring task is the need for effective data and information management. This is a traditional role for NOAA, and interagency planning has underscored the importance of our handling the massive amount of earth science data generated by the program in a way which will allow them to be used effectively for scientific research and assessment of change. We welcome the challenge. A strong interagency effort is being developed in order to plan for these data systems.

B. Another key to evaluating projected changes in global climate is the documentation of past changes, particularly over the last millennium, and the assesment of recurring changes and present trends through evaluation of extensive new climate data sets. While a great deal of quantitative information about past change from ice cores, sediment analysis, tree ring data and other sources exists, we have not yet illuminated in detail how the climate system has changed in the past and how it may presently be changing. Our program delineates an active role for NOAA in such a national effort. Our efforts in this regard began several years ago. One of the most useful data sets for evaluating changes in the earth's temperatures over the last century, for example, is a surface marine record prepared by NOAA from more than one hundred million obsevations taken since 1850.

Computer models of changing global climate, which will play a central role in the national program, cannot be validated in the usual sense for decadal or longer changes. One of the best tests for the validity of decadal predictions will thus be their ability to replicate past changes.

C. In order to achieve the predictive goals of the national program, it is necessary to make extensive use of numerical climate models to simulate future conditions. NOAA has, throughout its history, been a world leader in numerical modeling, beginning more than three decades ago with the application of numerical weather models for prediction purposes. Over the last decades, a major focus on climate modeling has produced in NOAA an unusually strong and flexible national resource for studies of global change. NOAA climate models have been used extensively over the last decade to increase our understanding of how the earth system works, and to provide quantitative evidence of the global significance of problems such as increased atmospheric carbon dioxide.

The figure here, for example, was derived from an experimental NOAA model of the global atmosphere-ocean system. This model provided some of the early insight into the strong regional differences in atmosperic warming due to projected CO_2 increases and demonstrated the substantial role of the ocean in modulating change. We have also begun recently to use climate models experimentally in an operational environment (at the National Meteorological Center), and the transfer of numerical climate modeling technology to operations is an integral part of NOAA's long-range plans.

D. NOAA also pursues a program of focused research into global climate change. It will take many years, even decades, to understand fully the global climate system

and to model it in its full complexity. Recent experience indicates, however, that it is possible to develop effective hypotheses about how climate changes, and, in some cases, to develop very limited predictive capability before we understand the total system. The work on El Nino and related global climate effects through the TOGA (Tropical Ocean and the Global Atmosphere) Program, and the progress being made in understanding radiative gases and their chemical reactions in the atmosphere through the RITS (Radiatively Important Trace Species) Program are effective, ongoing examples of this approach. The NOAA program of research will continue to pursue these activities.

The definition of a NOAA program in each of these four areas assum continued complementary actions in NASA, NSF, and other agencies, each I keeping with its role in the program. You have seen evidence today that interagency planning is well underway. With the completion of this planning and the establishment of program focus we have undertaken in NOAA, I feel confident in stating that we can and will do our part in the important new program area.

CONCLUSIONS

We have seen that there are pressing problems of the effect of climate change on society and there is a vital need to improve our knowledge base. We will continue to pursue a focused program with the objective of predicting earth system behavior, including particularly climate change, on societally relevant time scales. We are just beginning to learn the quantitative extent to which climate information can pay practical dividends. The problem is scientifically tractable; we have research strategies and implementing plans in place. We in NOAA intend to focus our existing resources and efforts on bringing all of the necessary elements together into a working information service—the long-term knowledge base for U.S. decisions on global change well into the 21st century.

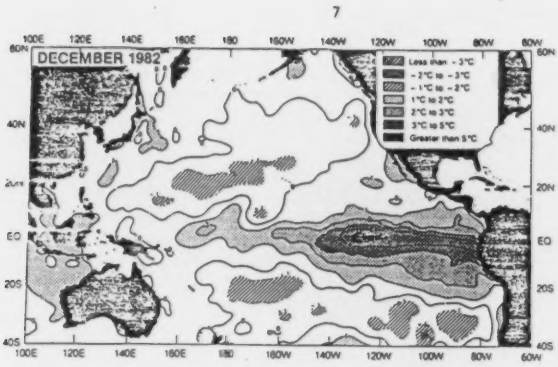


Figure 1. Sea surface temperatures in the tropical Pacific ocean, shown as departures from normal. Values in the eastern equatorial region exceeded 5°C above a normal December value. (Climate Analysis Center)

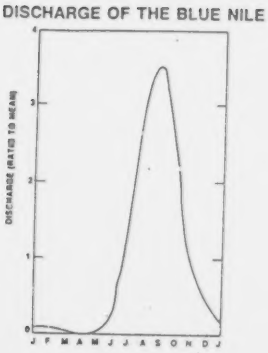


Figure 2. Annual cycle of Nile River discharge. From Climate and Man's Environment: An Introduction to Applied Climatology (J. E. Oliver).

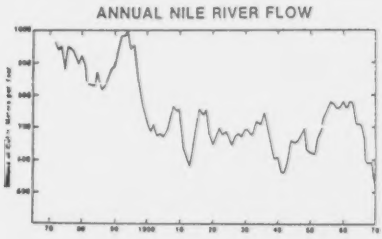


Figure 3. One Century of Nile River discharge. (J. O. Fletcher, personal communication.)

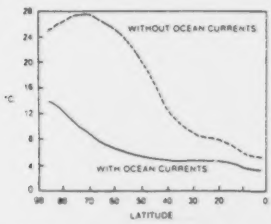


Figure 4. Simulated changes in atmospheric temperature due to a fourfold increase in carbon dioxide (Manabe, et al).

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Office of Legislative Affairs

OCT 30 1987

Honorable Ernest Hollings
Chairman, Committee on Commerce,
Science, and Transportation
Washington, D.C. 20510

Dear Mr. Chairman:

We are pleased to respond to your questions in followup to Dr. Michael Hall's July 16, 1987 testimony on global climate change.

If you, or your staff, require additional information, please do not hesitate to contact me.

Sincerely,

B. Kent Burton
Director

QUESTION 1:

As Congress is faced with the need to develop policies which respond to global environmental problems, we will need the best predictive advice available on which to base decisions. The U.S. Global Change Program can act as an invaluable resource.

- What procedures are incorporated into the proposed Global Change Program to keep Congress updated on major findings?

- What additional procedures would you suggest to improve the integration of scientific advances into policy development?

ANSWER: The new Committee on Earth Sciences (CES) of the Federal Coordinating Council on Science, Engineering and Technology (FCCSET) will have a key role in the planning, coordination and review of multiagency efforts in earth sciences. It is specifically charged to provide "reviews, analyses, advice and recommendations to the Chairperson of FCCSET on Federal policies and programs concerned with Earth Sciences Research and Development, particularly assessing humankind's impact on the global environment." The charter also calls for submission of an annual report on its activities to the Director, Office of Science and Technology Policy (OSTP). The annual and special reports of the CES have the potential of providing the government with the appropriate background information and policy advice needed to support effective response to global environmental problems. The CES is currently engaged in the process of identifying the most pressing specific issues for its consideration. The timing and nature of the formal CES reports have not yet been identified. Presumably, Congressional interest in receipt of such reports and/or suggestions on their structure could be communicated to the Director of OSTP, and the Chairman of CES. Of course, the Agency also will continue to keep Congress informed on an informal and ongoing basis.

QUESTION 2: Your testimony indicates that a major focus of the National Oceanic and Atmospheric Agency's (NOAA) global climate change initiative will be improvement of long-term climate prediction capabilities. However, earlier this year, news reports stated that U.S. weather forecasters are lagging behind their European counterparts in international efforts to improve global weather prediction.

- What is the relationship between weather forecasting accuracy and our ability to predict long-term climatic trends?

- Why is the U.S. forecasting ability lagging behind?

- What are the major programmatic or equipment needs required to improve our predictive capabilities?

ANSWER: To the extent that our ability to mathematically represent the physical processes of the atmosphere at our current state of knowledge limits our weather prediction capabilities, these limitations will be reflected to some degree in our potential for predicting long-term climate trends. However, the long-term climate prediction problem differs from the weather prediction problem in a number of significant ways, both in terms of the physical nature of the problem and in terms of the requirements established by the applications for such information.

Weather prediction, whether it involves forecasting for only a few days, several weeks, or longer, is concerned with representing the physical state of the atmosphere in the near future as precisely as possible, down to the local level of detail (mesoscale). The applications are characterized by a very limited set of possible responses, restricted by the short-lead time nature of the information. We need to know when, where and how much it is going to snow, when and where a hurricane will make landfall, whether a local agricultural area will experience a frost tonight, whether local flooding is a serious prospect this week, whether there is a serious risk of a tornado touching down in a given locale today, etc. Our responses are specific, and involve costly commitments of resources (snow removal) or other actions critical to health and safety (coastal evacuation, crop protection, harvest schedule). These applications of weather information are "tactical" in nature, much as actions taken on a battlefield when most of the forces are committed and in place. Therefore, the information needs to be as detailed and as accurate as possible. The physical/mathematical nature of the problem on the shorter weather time scales is dominated by the details of the state of the atmosphere (and to a lesser degree the surface layers of the ocean) at the point in time from when the prediction is being made: this requires highly accurate and detailed meteorological data over a given geographic area and the ability

to represent those atmospheric processes that govern the detailed evolution of the system. Also, the ability to extrapolate the detailed atmospheric state into the future is practically restricted by our computational (computer) capacities.

The long-term climate prediction problem, because it involves long-term and large scale processes in the atmosphere, ocean and land/ice areas of the earth, involves another set of problems. Prediction of the precise, local details of the state of the atmosphere at some far future date is neither possible nor necessary. Beyond a season or two, knowledge of the precise state of the atmosphere at the present time no longer dominates the prediction of the future state, but many more complex physical processes are involved than in the weather prediction problem (e.g., the dynamics and heat transport of the oceans). However, the applications are now dominated by the long lead time nature of the information and the larger spatial scales involved. The information is more qualitative, but of a "strategic" nature, offering a wide range of possible responses as far as applications are concerned. By strategic, we mean relationship to the broadest planning level concerned with the way resources are committed, the over all level of commitment of resources, and other long lead time actions taken to offset (or take advantage) of projected effects of climate change. For example, if we were able to project reliably that over the next decades there will be a gradual shift in the mean global temperature accompanied by a much higher frequency of extreme weather conditions, we could implement appropriate agricultural policies including development of new strains of plants resistant to weather extremes. Local governments would know whether to increase or decrease their snow removal budgets. Coastal communities would know whether to restrict coastal development, expand the road systems, or both. For actions of this kind, specific knowledge of the actual weather on any given day in some local areas many years from now is not particularly relevant.

The U.S. weather prediction capabilities currently are lagging behind the operations of the European Center for Medium-Range Weather Forecasts (ECMWF) because the Europeans recently increased the sophistication of the mathematical representations of atmospheric processes in their weather prediction computer models. Many of these advances were actually developed by the NOAA Geophysical Fluid Dynamics Laboratory (GFDL) at Princeton, but the Europeans were able to bring these on line earlier, because they acquired advanced supercomputer capacity.

The principal programmatic need to achieve this "strategic" climate prediction capability for the country is a coordinated interagency program of focused research and development directed toward that goal, and including the necessary global environmental monitoring systems (satellites and in situ monitoring systems), computers and information networks. The principal requirement for improving global weather prediction is the use of "next generation" supercomputers for operations and research.

QUESTION 3: The President's Office of Science and Technology Policy (OSTP) recently created a Committee on Earth Sciences, to be chaired by NOAA Administrator, Dr. Anthony Calio.

- What role will this committee play in coordinating the U.S. interagency program?

- What is the interaction between this committee and other scientific advisory groups such as the National Academy of Sciences?

- How well have the programs of other agencies such as the Department of Defense and Environmental Protection Agency been integrated into the U.S. interagency program?

ANSWER: The creation of CES recognizes that no single agency has the capabilities or resources to address the problems of global environmental change alone. Thus, from the Chairman's perspective, the key role for CES is the coordination of multi-agency efforts in earth sciences to ensure that the Federal government can respond to the increasingly complex issues of a changing global environment. Specifically, by providing guidance to the Director of OSTP and working through existing programs and policy, CES could:

- o provide a forum for coordinating agency science and technology programs and plans related to the U.S. effort in earth sciences;

- o coordinate a process leading to specific recommendations on near-term issues; and

- o provide a mechanism to identify future concerns as they emerge and coordinate the development of research programs and plans to ensure an adequate, timely and efficiently developed scientific basis for addressing those concerns.

The CES should take full advantage of existing policy formulation channels and work closely with the National Research Council and the emerging international framework for global change research. We believe that by providing scientific guidance to the Director of OSTP and working through existing program and policy channels, a coordinating forum like CES can ensure that the Federal government meets its responsibilities in responding to the increasingly complex issues of a changing global environment.

The Environmental Protection Agency has recently become an active participant in climate and global change problems, specifically related to possible impacts and regulatory issues, and is in the process of developing its own programmatic

contribution to the national program. It is a participatory agency in the CES. The Department of Defense has not been directly active in specific climate and global change programs, but is active in supporting data collection and technical information programs on an integrated interagency basis, e.g., the NOAA-Navy Joint Ice Center. It has also made DoD satellite data available, with restrictions, for climate and global change research efforts to other agencies, e.g., the Navy GEOSAT radar altimeter satellite mission and the Defense Meteorological Satellite Program (DMSP). However, the primary national security purposes of many of the DoD programs have resulted in classification restrictions in several instances on many of its data collection programs that have limited the full utilization of the information in civilian applications, including climate and global changes. Consequently, DoD participation in a national domestic climate and global change program will probably remain peripheral, except as a user of the information products.

QUESTION 4: The key to the success of the entire global environmental research effort may lie in the data management and information system. OSTP estimates that within the next decade, the satellite data flow will increase from 100 billion bits per day to over 10 trillion bits per day. OSTP suggests that the proper handling of all these data is probably the largest technological challenge to be faced in the U.S. program.

- What efforts are currently underway to successfully meet this challenge?

- What data-sharing arrangements are planned to move information efficiently among Federal agencies and to provide information to researchers outside the Federal government?

- With the increasing level of effort, do you foresee the need for a formalized sharing arrangement embodied in a memorandum of understanding among the agencies involved?

ANSWER: A key ingredient in the success of environmental research is proper management of program data and information. Due to long-time spans of observational programs, the diversity of data types (including very high data rate collection devices), and the numbers of investigators likely to be involved over the life of the program, this requirement is particularly critical in understanding global and climate change.

A number of data management efforts are presently underway to deal with this new age in environmental research. Federal agencies are emphasizing workforce productivity to deal with near-term, modest increases in data flow; interagency working groups have been convened to develop cooperative and innovative ways to ease the burden of acquiring, processing and archiving data from diverse and technologically advanced sources; and new types of information management technologies are being evaluated by key federal and academic institutions to cope with the expected explosion of environmental data. High speed electronic communication linkages are now being used to speed data across organization boundaries -- from collector, to data processor, and on to researcher. These networks will be further developed and their users expanded to support programmatic needs. Organizational arrangements among government, industrial and academic institutions are being developed to facilitate the sharing of environmental data required to provide new insights into the complexities of global and climate change. Formalized data sharing will certainly be required to expedite the movement of data and information among program participants.

NOAA has experience in managing operational data systems that feed our warning and forecast services. We are also working very hard to refurbish our archival systems to meet today's information needs and to prepare for the deluge of data to come from the future satellites. We are planning a data management system that will ensure the integrity of data as it passes from observation through collection, quality control, validation and into the data bases that serve as access and as archives. A part of the major effort to modernize our weather services, Automated Weather Information Processing System (AWIPS-90), includes plans for a major new dissemination systems (including satellite data) and upgrades in the processing of our environmental data into information. We are working very closely with NASA in planning of the information system that is a major part of the Earth Observation System of the Polar Platform of the Space Station. NOAA is interested in examining the platform as a potential carrier of operational sensors and in sharing the technology of the data management and processing systems.

The long term nature of climate and global change points to NOAA as a major data manager since part of our mission is to maintain the nation's environmental data. The interdisciplinary nature of the study of the earth as a system to understand its climate and its changes will require the close cooperation of several Federal agencies. For this reason, NOAA has convened an interagency working group to address the data management systems needed to accomplish the challenge of research into global change. The initial working group consists of Assistant Administrator level representatives from of NASA, NSF, USGS, and NOAA, with other agencies to be invited. The group is taking an inventory of the current data management capabilities of the agencies and identifying the additions needed to address the requirements of global change. The output is to be an integrated plan for the Federal data and information system. Several agencies already have substantial capabilities that need not be duplicated, but can be shared, and built upon. The group will also seek to learn of systems and talent for managing large data and information systems that are in the universities and in industry.

NOAA has existing memoranda of understanding with a number of Federal agencies involved in the global change effort. These agreements are "living" documents that are under regular review and modification as needed. They will serve as the basis for any increased "formalized sharing arrangement" that may arise due to this large effort.

QUESTION 5: I understand that ground observations are required to calibrate and validate satellite observations.

- What changes, if any, will be required in the present ground observation systems to provide adequate truthing for the planned expansion of our satellite systems?

ANSWER: *In situ* observations (whether at altitude in the atmosphere, in the ocean or land based) are generally needed to calibrate satellite instruments (remove certain instrument errors), verify and validate the remote observations on a continuing basis. In the case of satellite radar altimeters measuring sea level, in situ sea level gauges will provide support to the satellite orbital position determination operations.

The climate and global change applications do place some additional demands on in situ networks that will be used in complementary capacities with satellites. First, the demand is for truly global coverage. In most cases, in situ networks will require some expansion to meet this requirement. Also, siting of in situ stations will have to take into account the particular nature of environmental signals of concern; for example, many existing tide gauge sites world wide are located in estuaries, and so are not representative of the ocean level. The long-term concerns of climate and global change require accurate, regular observations over many decades that can be referenced to common and consistent standards and related to position. In many cases, continuous records are desirable. Hence, the in situ networks must also provide continuity, backup and referencing for satellite systems between satellite missions, in the event of satellite failure or mission maneuver, and to assess atellite instrument drift.

QUESTION 6: As you are well aware, NOAA is currently operating under severe funding constraints, requiring difficult budget decisions.

- What would be the impact of eliminating LANDSAT funding on the global climate initiative?

- How would the initiative be affected by dropping one of NOAA's two polar-orbiting satellites?

ANSWER: The data from the LANDSAT system are of value to the research goals of the NOAA program and to certain aspects of the larger national program. Of the satellites planned for the early 1990's, only LANDSAT provides the spatial and spectral resolutions needed for research. Data could be purchased from the French SPOT system, but it would not have the requisite spectral resolution. An alternative is to await the launch of the high spatial and spectral resolution sensors for research planned by NASA in the late 1990's on the Polar Platform of the Space Station. LANDSAT is presently the global observing platform providing the high resolution observations critical to long term climate research. The current archive of data along with that to be gathered in the next decade and archived in the LANDSAT formats will provide the continuity and long term data records required for research into changes on the global time and space scales. The higher spatial and spectral resolution of the LANDSAT data allow monitoring of changes in urban land use, forest types and harvesting, effects of agricultural practices, changes to living habitats and desertification. These data also will provide verification of and more detailed studies of changes that are detected by the meteorological satellites.

Today, the second polar orbiting satellite is absolutely essential as the "hot spare" that assures continuity of data and services to the operational users. The need for launch of a replacement satellite within 120 days of a satellite failure in orbit cannot be met today. Two polar-orbiting meteorological satellites are essential to the global change research as they are the global-observing systems that provide the long term temperature, vertical temperature structure and cloudiness. The observation of these parameters four times a day from two meteorological satellites decreases the time biases resulting from only two views a day from one satellite, and increases the chances that phenomena such as snow cover and other surface phenomena can be observed beneath ever-changing cloud cover.

Answers to Follow-up Questions from Senator Pressler for the Record of the July 16, 1987 Hearing on Global Change

QUESTION 1:

With our national budget deficit pressures increasing year-by-year, what is the urgency for initiating now a national program of "Global Change" -- why should this program assume such a high national priority?

What are the likely consequences and risks if we do not initiate a Global Change program, particularly with respect to ozone depletion and the greenhouse warming effect?

ANSWER: The climate research over the last several years has clearly established that man's activities have reached a level where they can affect the global climate system, but the ways that man's effects will interact with the natural variation of the climate system are not adequately understood. For example, we know that carbon dioxide produced by burning fossil fuels, as well as other atmospheric pollutants introduced by civilization will tend to increase the amount of sunlight converted into heat within the climate system. One effect that we might expect is an increase in average global temperatures, and indeed a consistent gradual global warming over the last 100 years or so has been observed. However, how the observed increase in global temperatures may also relate to the end of the natural climate cooling period known as the Little Ice Age (about 1350-1850 AD) is not understood. How global cloud cover (which may counteract the greenhouse mechanism) is being affected is not understood, either. Also, the greenhouse mechanism may also tend to energize the global climate system, increasing the magnitude of the shorter time period climate variations (variability). Our understanding of this climate variability is currently poor, even though this variability may have much more serious effects on man, at least on the near term.

Similarly, we know that certain atmospheric pollutants tend toward chemically destroying atmospheric ozone, and a definite reduction of atmospheric ozone over a number of years has been observed. However, the phenomenon and the processes involved are very complex and are probably coupled with inadequately understood natural climatic system processes, making assessments of the full implications of the observations difficult at this time.

There are many disturbing things about the global climate system right now. We cannot afford to be uncertain about the nature, magnitude, and future trends of nature's or man's effects on climate. We cannot afford to ignore the implications for the

Nation and the world, budget deficits notwithstanding. The price of ignorance may be an extreme loss in world-wide food production and serious threats to human health. The need to improve our understanding of, and ability to predict, global climate change has been recognized for decades. The urgency, the technological capability, and the scientific maturity now allow for mounting an effective research effort that will provide the knowledge imperative to secure a safe and productive future environment.

QUESTION 2:

I understand that the interagency Committee on Earth Science, chaired by NOAA Administrator Tony Calio, has begun to meet to formulate a national strategy for Global Change.

What fundamental assumptions will direct this Committee's consideration of a strategy for a national Global Change Program?

When should this Committee complete its work, and what can we expect as the product of this Committee's work?

ANSWER: The creation of the Committee on Earth Sciences (CES) of the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET) recognizes the fact that this is an exciting and critical time for global earth sciences:

- the scientific community is poised for truly revolutionary advances in our ability to understand and predict changes in the global earth system; and
- we are already facing major policy decisions associated with perceived changes (whether current or anticipated) in that global earth system.

As the current negotiations on ozone-depleting substances demonstrates, this Nation and the world must be in a position to make carefully considered decisions on the very real issues associated with changes in the global environment -- whether natural or man-made.

The creation of CES recognizes that no single agency has the capabilities or resources to address the problems of global environmental change alone. Thus, the key role for CES is the coordination of multiagency efforts in earth sciences to ensure that the Federal government can respond to the increasingly complex issues of a changing global environment. Specifically, by providing guidance to the Director, Office of Science and Technology Policy (OSTP) and working through existing program and policy, CES could:

- o provide a forum for coordinating agency science and technology programs and plans related to the U.S. effort in earth sciences;

- o coordinate a process leading to specific recommendations on near-term issues; and

- o provide a mechanism to identify future concerns as they emerge and coordinate the development of research programs and plans to ensure an adequate, timely and efficiently developed scientific basis for addressing those concerns.

The Committee's charter calls for submission of an annual report on its activities to the Director, OSTP. In addition, the Committee will submit periodic reports to the Director on specific issues, either at his request or as a result of Committee deliberations. The Committee is currently engaged in the process of identifying the most pressing specific issues for their consideration. The timing and nature of such reports have not yet been identified.

QUESTION 3:

What are the largest challenges in formulating a sensible national program and in achieving the goals and objectives of the program?

ANSWER: The greatest challenge for a national global change program will be the structuring of a program capable of achieving, within a reasonable schedule, reliable predictions, warning and assessment services for climate variations over the major time-scales affecting man (seasons to centuries). The influences of man's activities within the natural system's capacity to change must be first understood; this is the prime research goal. The results of the research must be effectively directed into the development of the required services. The development goal of the NOAA program is structured along these lines, but will require the result of other agencies' research and development goals. The national program needs to be structured in the same way, and effectively integrated to achieve practical information service goals (assessments, warning, and prediction). A national program requires clear recognition of need for such a program, statements of goals and objectives, strategies of program implementation, and measures of program success. These must all be largely agreed to by participating agencies; this is another challenge, and one which is being met.

QUESTION 4:

What institutional framework would allow for an effective, coordinated interagency Global Change program -- one that would

optimize the potential for synergism between the involved agencies and also minimize or eliminate unnecessary duplication of effort?

ANSWER: The implementation of an effective national effort to understand, predict, and respond to changes in the global environment requires the coordination of individual agency programs in a manner which takes advantage of each agency's unique mission, capabilities, and expertise. Such coordination requires the participation of agency leaders in a forum which allows them to focus on the functional elements of a scientific program in global change (e.g., scientific understanding of the processes involved, global measurements, data management, predictive model development, and validation).

The newly-created Committee on Earth Sciences can provide such a forum. CES can assist agency leadership and the Director, OSTP in assessing deficiencies, developing criteria to set priorities, and evaluating alternative courses of action to address those deficiencies.

The CES should take full advantage of existing policy formulation channels and work closely with the National Research Council and the emerging international framework for global change research. We believe that by providing scientific guidance to the Director, OSTP and working through existing program and policy channels, a coordinating forum like CES can ensure that the Federal Government meets its responsibilities in responding to the increasingly complex issues of a changing global environment.

QUESTION 5:

What total resource commitment would be required over the next five years to support a Global Change program? Ten years?

What total resource commitment from NOAA would be required over the next five years to support a Global Change program? Ten years?

What is an approximate five-year funding profile for NOAA's role in Global Change?

ANSWER: The specific nature and timing of the results of such a program to understand and predict global environmental change are, needless to say, related to the level of resources available and the degree of integration among program elements and participants. Based on our current level of understanding and scientific and technological capabilities, an aggressive, comprehensive national effort to address the complex issues of global environmental change could be undertaken with a direct commitment of at least $1 billion over the next 5-10 years, recognizing that this includes a fairly substantial investment in

satellite instrumentation and missions like the Navy Remote Ocean Sensing System (N-ROSS) and The Ocean Topography Experiment (TOPEX). This level includes resources already being directed at the problem.

Like the national effort, the nature and timing of benefits derived from NOAA's contribution to a program in global change will be related to the level of resources available to support the program. NOAA's contribution to the national effort focuses on providing reliable assessments and quantitative projections of climate change, builds on a strong base program in global observation and monitoring; data management; focused research and climate modelling and diagnostics. Any resources identified to support a focused program in global climate change would be used to leverage the full resources available within NOAA to address this problem. The specific level of resources to such a program is currently being discussed as part of the FY 1989 budget deliberations. A sustained program over ten years would involve the investment of around $700 million. Such a program assumes a first-year investment of between $30-50 million which approximately doubles by the second year and is sustained at that level thereafter.

QUESTION 6:

To what extent might we anticipate outside participation from private entities, such as laboratories, institutions, and industry in a Global Change program?

ANSWER: The NOAA program will involve allocation of a definite portion of its funding for support of a competitive extramural research program. In addition, most of the technology employed in the monitoring program will be supplied by private industry. The national program will involve a large extramural research and development effort within private and State-based institutions and laboratories funded by the National Science Foundation and a substantial technology development and implementation effort for the satellite remote sensing efforts funded by NASA. The latter will entail substantial expertise from the private sector.

QUESTION 7:

Concurrent with the U.S. Global Change initiative, the International Council of Scientific Unions has formulated the International Geosphere Biosphere Program (IGBP), which is also designed to conduct an interdisciplinary study of the changing global environment.

How would a U.S. Global Change program be effectively coordinated with an International Geosphere Biosphere Program, and what are the challenges and likely problems in coordinating the two programs?

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What duplication is likely to exist in the two initiatives, and how can such duplication be minimized or eliminated?

ANSWER: Details of coordinating a U.S. Global Change program with IGBP should be derived jointly by all participating agencies. The forum for this should be the CES. The CES can coordinate U.S. activities in Global Change, formulating plans and reporting on progress, aimed at U.S. priorities. The newly-formed committee within the National Academy of Sciences (NAS) to coordinate U.S. scientific activities with the IGBP, the NAS Committee on Global Change (CGC), can provide the interface between the U.S. governmental views expressed by the CES and the international scientific community.

Problems usually arise when international priorities do not coincide with domestic priorities. The greatest challenge is to identify where these priorities do coincide, and to negotiate a fair sharing of international responsibilities because each participating nation will be trying to match domestic with international science priorities under IGBP.

The U.S. global change activities can be considered a direct contribution to IGBP activities. There is great incentive to avoid duplication in the two initiatives due to limited fiscal resources. The coordination of the two programs through the governmental mechanism (the CES) and the international science mechanism (the CGC) will be the greatest help in avoiding duplication.

QUESTION 8:

Much of the thinking that has gone into a U.S. participation in an International Geosphere Biosphere Program (IGBP) was predicated on use of the Shuttle.

To what degree might a lower annual Shuttle flight rate and greater reliance on expendable launch vehicles (ELVs) affect the timing and extent of U.S. participation in the IGBP?

ANSWER: The Department of Commerce (DOC) does not perceive any delay in its satellite programs due to nonavailability of the Shuttle. The DOC has always utilized ELVs for launch of its polar and geostationary satellites. At present DOC is coordinating with Department of Defense (DOD) for launch of its future polar spacecraft (thru 1995) utilizing ELVs to be launched from Vandenberg Air Force Base, California. NASA is currently procuring commercial ELV launch services for DOC's GOES I through M series of satellites, the first of which is scheduled for launch in late 1989. The GOES I-M satellites will be launched from Cape Canaveral, Florida.

QUESTION 9:

Are there lessons that have been learned from conducting or participating in other large international science programs that might benefit the U.S. in terms of setting up an International Geosphere Biosphere Program itself and in establishing the national and international organizations?

ANSWER: Yes. The United States has been a major participant in the Global Atmospheric Research Program (GARP) which included major field experiments such as the GARP Atlantic Tropical Experiment (GATE) and the First GARP Global Experiment (FGGE), also known as the Global Weather Experiment. GATE was unique in that the day-to-day planning and execution involved personnel, ships, and aircraft from several countries. Daily operations for FGGE, on the other hand, were generally conducted by individual countries as part of a larger international plan. The compilation of this data into comprehensive data sets capable of being used by a variety of researchers were monumental tasks. Both programs were highly successful.

Although the international aspects of the Tropical Ocean and Global Atmosphere (TOGA) Program are still in their infancy, the management structure is being patterned after the GARP experiments. The U.S. TOGA Program, now in its third year, draws heavily on GARP expertise and has already achieved successes and garnered accolades from the academic community. It is envisioned that the International Geosphere Biosphere Program (IGBP) scientific coordination and management organizations, both nationally and internationally, will be designed based on the GARP and TOGA experiences. Specific lessons learned are the need for a central project office which, acting on the advice and consent of other established bodies, controls the program resources and the need for a strong data management program.

QUESTION 10:

Will the Federal agencies rely solely on the National Academy of Sciences Committee on Global Change for guidance and expert advice as to how to steer their respective contributions to the Global Change program? If not, then through what other channels?

ANSWER: The Federal agencies will utilize a number of boards and panels of the National Academy of Sciences, for example the new Committee on Global Change, the Board on Atmospheric Sciences and Climate, the Ocean Sciences Board, and the Climate Research Committee. However, other review mechanisms will also be utilized. The primary peer review system for the NOAA component of the program will be a stand-alone advisory panel being formed under the auspices of the University Corporation for Atmospheric Research (UCAR).

QUESTION 11:

One of the keys to the success of a Global Change effort is the proper management of the data and the establishment of adequate information systems that have an evolutionary capability?

Which agency or agencies should take the lead in managing the data and in establishing the information systems?

ANSWER: Data management is one of the keys to a successful climate and global change effort. This is because a data management program would ensure the integrity of data as it passes from observation through collection, quality control, validation, data base archiving, and access. For global long-term programs like those involving climate and global change, these data management elements, for satellite and in-situ data alike, are absolutely essential for successful analyses and forecasting. To help manage these elements, the Federal data and information systems must have an interagency as well as evolutionary capability. No one agency can afford to build a data and information system for climate or global change, at the exclusion of other agencies.

Because the climate and global change programs are very long term, like the GARP and TOGA experiments, their data management naturally falls to NOAA, whose mission encompasses maintenance of environmental data. On this basis, NOAA has already called together an interagency data management working group for global change. This working group, consisting of high level representatives of NASA, NSF, USGS, and NOAA, with other agencies to be invited, will take an inventory of the agencies' data management capabilities; identify the gaps in their systems, particularly with respect to satisfying global change requirements; and propose an integrated plan for a data and information system. Because different agencies have made substantial progress in various elements of data and information systems, this working group will take advantage of these existing systems as well as the existing talents in universities and industry.

QUESTION 12:

What are the national security implications and considerations in establishing a Global Change program and in U.S. participation in an International Geosphere Biosphere Program?

To what extent is the Department of Defense or any other national security agency expected to participate in a Global Change program?

ANSWER: National security concerns are inherent in global change issues. One need only consider the potential consequences of global and regional drought cycles on agriculture and animal

husbandry in the U.S. Grain Belt, the Ukranian SSR, and the Sub-Saharan Africa; the impact on water resource issues in the U.S. far western states or on Egypt, the Nile and the Middle East; or the energy implications of any protracted global warming/cooling. The relative economic strengths of nations, their internal political stability, and their relationships with neighboring countries are all strongly affected by such issues. Consequently, the Department of State and other agencies involved in national security issues should be interested in global change information, including the data collected through international climate observation systems involving, among a host of climate parameters, land surface moisture exchange properties and ocean temperatures, tides and currents. DOD, to the extent that it participates in the joint gathering and distribution of environmental information, such as the NOAA-NAVY Joint Ice Center, will lend support to the effort.

QUESTION 13:

Will U.S. plans for a Global Change program be embodied in an official statement of national policy, and how will a determination be made as to whether sufficient budgetary support has been committed to the program?

ANSWER: Given the multi-agency scope of the global change program now unfolding and the high level of Administration sanction already given to it, it remains possible that some form of official Presidential statement of national purpose or goal concerning the global change effort will be made at some future date, as was done in the case of other major U.S. scientific commitments such as GARP. White House support of the program is implicit in the President's FY 1988 budget submission to the Congress, which includes funding for NSF and NASA elements of the program.

The highest level formal Administration policy statement to date is contained in a March 6, 1987, White House memorandum for FCCSET from William R. Graham (attached) which officially issued the charter for a new "Committee on Earth Sciences". The cover memorandum and CES charter have been distributed to six departments of the government, the independent national science agencies, OMB and the CEQ. Extensive excerpts were published in Ocean Science News (Vol. 29, No. 16, April 28, 1987). The lead paragraph under "purpose and functions" (of CES) within the charter states:

> A goal of Earth sciences is to understand, on a global scale, how the highly interactive system comprised of the solid Earth, the oceans, the atmosphere and magnetosphere and the biosphere has evolved, how it functions today, and how it will evolve in the future. In addition to the basic research, important components of Earth science R&D include continued development of the technology for needed observations of the Earth system and increased emphasis on

collection, analysis and archival of data on a global scale from satellite and ground-based measurements needed for long-term research efforts and also needed to address national policy issues which depend on a characterization of humankind's impact, or potential impact, on the global environment. The purpose of the Committee of Earth Sciences is to increase the overall effectiveness and productivity of Federal R&D efforts directed toward an understanding of the Earth as a global system. In fulfilling this purpose, the Committee addresses significant national policy matters which cut across agency boundaries.

The statement elaborates certain specific functions of the CES:

a. reviews Federal R&D programs in Earth sciences including both national and international programs;

b. improves planning, coordination, and communication among Federal agencies engaged in Earth sciences R&D;

c. identifies and defines Earth sciences R&D needs;

d. develops and updates long-range plans for the overall Federal R&D effort in Earth sciences;

e. addresses specific programmatic and operational issues and problems which affect two or more Federal agencies;

f. provides reviews, analyses, advice, and recommendations to the Chairperson of FCCSET on Federal policies and programs concerned with Earth sciences R&D, particularly in assessing humankind's impact on the global environment.

CES conduct of these itemized functions will provide a national ongoing basis for determining whether sufficient budgetary support has been committed to the national programs.

QUESTION 14:

By what standards should a U.S. Global Change program be measured, and what should be the measure of "success" in this program?

For what scientific reasons might it be necessary to discontinue a Global Change Program after it is initiated, or, put another way, is there a quantitative or qualitative threshold that such a program should meet in order to justify its continuation?

ANSWER: NOAA is in the process of formulating its contributions to a U.S. Global Change program. The NOAA mission gives it a unique range of responsibility to develop and provide a range of environmental and other technical information services, including

predictions, warnings and assessments. Consequently, it is the only federal agency involved in the complete process starting with basic data collection, and going through applied research and development and ending with provisions of archival data and advanced information service (including predictions and assessments). Because of this scope, the problem of formulating the NOAA program strategy and determining measures for its success, can serve as a model for approaching the entire integrated national program.

In this respect, the key to the NOAA program is identification of a central goal and associated subgoals, i.e., the provision of predictive information on climate and global change covering a range of time-scales for which important changes are known to take place. This range is defined to cover seasons through a few centuries, and is based on both the physical nature of change in the climate system itself, and the practical value of such information to society. Achievement of this goal determines the design of the components of the NOAA program and priorities, and allocation of resources within it.

The long-range objectives involve a 20-year program, but major milestones and associated time-lines will be built into the program to provide a sequence of practical accomplishments. The status of the specified milestones at various points along the time-line provide a means of evaluating the program. An evaluation system (including external advisory and review mechanisms) and an active ongoing planning process and management system to direct programmatic changes are all included within the NOAA program. Any necessary redirections or adjustments (including scale-back or terminations) are built into the program review process. Meeting the minimum qualitative and quantitative requirements of critical milestones will provide base threshold to ustify continuation of the program. The same overall goal and similar programmatic concept can be applied to an integrated national effort. The interagency nature of the national program would require more complex management, planning and review mechanisms, but a major start in that direction has already taken place with the establishment of the CES under FCCSET.

QUESTION 15:

It is widely understood that satellite land remote sensing will play an important role in a Global Change program.

Just how critical will satellite land remote sensing data be to the success of such a program?

How important is a U.S. satellite land remote sensing capability to a Global Change program, and to what extent would a U.S. commercial land remote sensing capability be able to meet these national requirements?

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To what extent should the U.S. be expected to rely on satellite land remote sensing data from foreign satellite systems -- would this be a practical option if there were no U.S. Landsat system?

ANSWER: Monitoring change on the Earth's land surface is an important part of any program to monitor global change. Some changes at the land surface, such as snow cover and sea ice extent, vegetation characteristics over time, albedo, etc., should be easier to detect from space. Meteorological satellites are ideally suited to provide most of the data for monitoring land surface climate phenomena under the Global Change Program. The combination of relatively low resolution and daily revisit time of meteorological satellites allows global coverage with a tractable data volume. The sensors on the weather satellites make observations of the surface in the appropriate spectral bands for monitoring vegetation, snow and ice, and land surface characteristics.

The land remote sensing satellite systems of the U.S. (Landsat) and France (SPOT) provide a needed complimentary capability to the meteorological satellites. Landsat and SPOT have a low revisit rate (every 16 days for Landsat), however, these satellites do provide much higher resolutions, both spatially and spectrally, which allow mapping and monitoring of certain land features and processes that cannot be discriminated with meteorological satellite data. Examples are monitoring changes in urban land use, detailed agriculture and cropping patterns, forest types, wildlife habitat, and desertification. Another use of Landsat type data in a Global Change Program will be verification of phenomena first detected by meteorological satellites.

If Landsat data were not available, some global change requirements for higher resolution data could be met with SPOT data. This option, however, would be more costly to the U.S., both in data expenditures and in loss of technology.

QUESTION 16:

Similarly, how important would the capabilities offered by EROS Data Center be to a Global Change program, and how might the functions of this facility be expanded to support a Global Change program?

ANSWER: The archival, data processing and analysis, and research capabilities that exist at the EROS Data Center (EDC) could all contribute to a Global Change Program. The remotely sensed and land resource data bases currently archived, and future acquisitions, would be useful to any retrospective, or planned, research efforts included in the program. EDC could conceivably be relied on as an integral part of the data management plan for this program.

The results of ongoing research activities at EDC that include improved methods to process, merge, and analyze remotely sensed and ground-based data of the Earth, are applicable to data acquired as a part of this program. The research activities at EDC that include the development and application of techniques to utilize remotely sensed data to assess and monitor natural resources of the United States could be expanded to global scale. Developed methods for resource monitoring and assessment have already been applied internationally by scientists at EDC. Two recently established programs between the U.S. Geological Survey and NOAA, at the EROS Data Center, could directly support the Global Change Program. The collocated National Satellite Land Remote Sensing Data Archive and Cooperative Federal Land Remote Sensing Research Program, if expanded as planned, could be vigorously involved in the Global Change Program.

QUESTION 17:

Is the U.S. scientific academic infrastructure of high schools and colleges sufficient to support such a national Global Change initiative, not only with research but also with a steady supply of qualified scientists?

If not, what is being done to address this deficiency?

Do human resource problems exist on an international scale?

ANSWER: The national and international scientific communities are ready to begin an attack on the problems of changes in the global environment. Much of that talent resides in the colleges and universities of the U.S. and throughout the world. In the long-term, however, the Federal Government, primarily the National Science Foundation and Department of Education, must undertake a concerted program to build the intellectual scientific base in the United States. Availability of resources to support academic scientific investigators, through a national global change program will enable them to entrain the talent of their students. This will help to broaden the pool of scientific talent available to address the problem and ensure building of a future base of appropriate intellectual resources.

In addition, as a "Global Change Program" provides a greater understanding of how the global earth system operates, these new insights will be passed on through the formal education system including high schools and colleges. This process should create an intellectual environment that enables tomorrow's student-scientist to focus their talents even more effectively on the complex scientific problems associated with understanding and predicting global environmental change. As a leader in the international scientific community, the United States should ensure that the planning and implementation of our contribution to

a program in global change includes specific elements designed to strengthen the necessary intellectual resources here and abroad.

QUESTION 18:

What, if any, technologies need to be developed to adequately address the issues that are central to Global Change, and what level of federal investment would be required to develop these technologies?

Similarly, how great an investment in national facilities must be made to support a Global Change initiative?

ANSWER: The NOAA portion of the global change program is not dependent on any major technological developments. Where development is involved, it either:

a. is already funded by NOAA or other federal agencies and private industry, supporting other requirements and mostly in an advanced state of progress

b. involves a further (more advanced) step to be supported by a NOAA global change program in development efforts already ongoing in NOAA

c. involves later scheduled stages in the program, so that adequate lead-time is involved for required development

d. can be anticipated as a more-or-less off the shelf item from commercial sources within the program time-lines.

No more than about 10-15 percent of the NOAA program is estimated to be involved in what could be called technology development, excluding satellites.

Other components of the national program are much more involved with technology development, e.g., NASA. However, these also are generally not involved with any high risk major breakthrough systems. Development, while at the state of the art, does not involve major advances beyond it, and the national global change program is not perceived to be vulnerable to failures in meeting requirements or schedules in any one systems development effort.

National facilities investments generally involve computer upgrades, some specialized equipment procurements (especially field equipment), software development, etc. For the NOAA program, such investments are estimated to amount to 20-50 percent of the various elements of the program, excluding satellites. The national program percentages can be expected to be higher for agencies such as NASA when funding for satellite systems is included.

Senator GORE. Thank you very much. I appreciate all three of you appearing. Let me just ask a few questions, because the hour is late.

NSF was the principal sponsor of the Antarctic expedition on ozone. Is that correct?

Dr. CORELL. Actually, it was a marvelous example of cooperation, and agencies getting together.

NSF, of course, operates the Antarctic program and provides the major logistic base of support. NOAA came through with a major scientific effort. NASA was a partner. The Chemical Manufacturers Association, and universities also contributed.

Senator GORE. All right. Fine.

Dr. CORELL. The important thing is we were able to do it in a very short period of time. Together we mounted a major experiment within a few months time.

Senator GORE. Very good. I had thought you all were the lead agency because you have been down there with the Antarctic program. But of course it was a cooperative venture.

When do you expect the final report of that expedition?

Dr. CORELL. Well, the reports are coming out, as you mentioned earlier. Scientific papers, special workshops.

I think the science community tries very hard to get that information out as soon as they possibly can. The early results are in papers, available to us. I think we will see it not in one comprehensive report, but a series of reports and papers.

Probably one of the most important things that came out of NOZE was an attempt to better understand the variety of theories and strategies as to how stratospheric ozone depletion might occur, so that we can design the next phase of experiments, which we mentioned earlier are about to be mounted within weeks.

Senator GORE. In other words, you are going back to Antarctica within a short period of time.

Dr. CORELL. Yes. We are going down as soon as we can possibly fly the first aircraft into that continent, which is August 26.

Senator GORE. When does the austral spring begin?

Dr. CORELL. About then. That is the first time we fly in, and that is the beginning of the austral spring in the Antarctic region.

Senator GORE. And the ozone hole appears about then as well.

Dr. CORELL. It starts developing sometime in August and continues to grow into October. I do not know whether NASA or others might want to comment about the effect itself.

We do have Bob Watson here who could give you a bit more scientific data on that, if you would like to explore that, Senator.

Senator GORE. All right, fine. Could he join us at the table?

Mr. WATSON. Thank you, Senator.

Senator GORE. Now, you know about this data from Antarctica. Do you not?

Mr. WATSON. Correct. Very well. I am also writing a report that will bring together all the data. We hope to have a final report by probably mid-November. We will also have a report of what will occur this year.

What we found last year at McMurdo was fundamentally the chemistry was highly perturbed. Very high concentrations of chlo-

rine. Very low concentrations of nitrogen. These tend at first sight to automatically support the fluorocarbon theory.

There are three basic theories proposed so far to explain the Antarctic phenomena. One is man-made, the fluorocarbon theory. One is a natural solar cycle theory. And one is a change in the normal meteorology.

Senator GORE. Change in the what?

Mr. WATSON. Meteorology, the dynamics, the meteorology, the circulation of the atmosphere.

Senator GORE. All right. Yes.

Mr. WATSON. All the data suggests the solar theory is incorrect. The low nitrogen is totally inconsistent with that theory.

That leaves the two theories, the fluorocarbon theory and the natural meteorology theory. All the scientific data strongly supports the chlorine man-made theory. However, I personally believe it is premature to conclude it is definitely fluorocarbons.

However, this year, not only is NSF sponsoring another campaign to McMurdo. NASA, in collaboration with the other agencies, is taking a high-flying ER-2 aircraft to Punta Arenas in Chile.

We are also taking a DC-8 to Punta Arenas in Chile. We have about 20 very state-of-the-art instruments. We will fly directly into the Antarctic hole, and we will almost certainly, in my opinion, prove or disprove whether the Antarctic ozone hole is caused by fluorocarbons.

So it will be a much more definitive experiment. Highly complementary to what we have done already. We plan to come back from there on October the 1st. We plan to come back with a short report that can be used either for Congressional testimony or as a press release.

So we would hope that by about October the 1st of this year to be able to give you some very strong information of whether it (the Antarctic Ozone Hole) is man-made or not.

We may not be able to tell you another issue that you would like to understand fully. What is the probability for having global consequences? We will have some more information on the global consequences. But I doubt if this one campaign alone will provide all the answers.

Senator GORE. Are you familiar with the July 10th article in Science magazine about stratospheric ozone depletion?

Mr. WATSON. Which one is that? There have been so many recently.

Senator GORE. Yes. Just to summarize it briefly, and you correct me if I somehow misstate it.

The primary satellite monitor used to measure stratospheric ozone and the ground-based instruments used to measure stratospheric ozone, and here we are talking about not the ozone hole, we are talking about the ozone layer over Washington, D.C., the United States, Europe, the entire world.

The best instruments we have, which are not that good, the best instruments we have now indicate a depletion of ozone over the rest of the world at a rate twice as fast as the models predicted.

And although there is tremendous dissatisfaction with the instruments we use to measure the ozone depletion over the rest of the world, nevertheless, all of the information available tends to in-

dicate now that we are seeing a rather rapid decrease of ozone over the rest of the world.

Is that a fair summary of this? Or how could you improve it?

Mr. WATSON. Yes. That is a fair summary. The only improvement I would make is if anything, the rate of decrease from 1979 to 1987 is probably five to 10 times faster than you would predict from the fluorocarbon theory.

I think there are two factors here. How good is the data? There is a group of 100 scientists worldwide analyzing critically how good that database is. At this moment in time there is no reason to believe that the decreases observed from Nimbus 7 or from the Dobson Station are incorrect.

But then the following question is a very important one. And that is, is this decrease from 1979 an indication that fluorocarbons are far worse that we previously thought, or is it partly just natural variability?

We should point out that the amount of ozone in the globe in 1960 was also an all-time low. It went up 4 percent from 1960 to 1970, stayed constant through the 1970s, and has dropped by 4 or 5 percent.

So what we are trying to do is, we are trying to simulate the whole 30-year record to see if we can differentiate the natural variability from that caused by fluorocarbons.

Senator GORE. Well, almost 15 years ago, the first scientists predicted that we would see this result. Then we discovered, to our dismay, this hole in the ozone in Antarctica, which caused the emergency expedition and another expedition this year.

Now all the available data confirms another prediction, tends to confirm another prediction. And that is a depletion of ozone in the rest of the stratosphere. But you think we will know more soon?

Mr. WATSON. I think the way I would summarize it is the following.

I believe there has been a decrease in ozone near 40 kilometers, highly suggestive of fluorocarbons. There may have been a decrease globally, probably has been a decrease globally.

We cannot differentiate between natural variability and fluorocarbons at this moment. There certainly has been a large, unexpected decrease in ozone in Antarctica that was a complete surprise to everybody.

One thing that stayed totally robust in our theoretical calculations is simple. If you put chlorine into the atmosphere, it will destroy ozone. Very different from the nitrogen-methane situation.

Even in the laboratory, we cannot put chlorine in the presence of ozone and make ozone. It always destroys it. So it has been a very robust theoretical finding and laboratory finding.

That is, if you put chlorine or bromine, fluorocarbons or halons into the atmosphere, we are highly likely to destroy ozone.

Senator GORE. All right. Very good. Now, please stay with us there, Mr. Watson.

Dr. Fisk, Mr. Hall, excuse me. I asked an earlier witness about this recent news report, which I do not fully understand.

The Cox News Service reported that NOAA computers had been used to analyze the satellite imagery taken since 1973, and that analysis has uncovered more than 200 incidents, just since 1973,

when very large, presumably methane, plumes have been released in the Arctic.

And the speculation by the scientists is that warming of the ice pack is responsible for the release of methane trapped in prehistoric times.

Can you shed some light on this news report?

Mr. HALL. Actually I cannot shed a great deal of light on it.

It is possible to look at stored satellite images over the last several years and perceive plumes that may be sources of methane gas.

Discussion of the cause for such a release has to be considered speculative at this point.

I do not know if the problem has been examined in detail. If you would like, we can certainly prepare an answer and submit it to you either informally or for the record.

[The following information was subsequently received for the record:]

Since 1973, plumes from Bennett Island, U.S.S.R., often hundred of kilometers long and tens of kilometers wide, have been detected on satellite imagery. They are usually at low altitude and appear colder than the surrounding air. Although ground measurements have not been made to determine the cause of the plumes, they are probably produced by release of methane from the ocean bottom. If this is indeed the cause, the methane release, which seems to occur rather frequently, could be a major source of the observed global methane increase. Because methane is a greenhouse gas, verification of this area as a methane source needs to be undertaken.

Senator GORE. Yes. I wish you would. And a Michael Matson, with your agency, is quoted in this article. So you might ask him to participate in that.

Mr. HALL. Yes, sir.

Senator GORE. I would appreciate that. How soon are we likely to resolve this uncertainty about stratospheric ozone?

Mr. WATSON. It depends exactly which uncertainty you mean. If it has to do with Antarctic ozone——

Senator GORE. No, no. The more broadly-distributed ozone.

Mr. WATSON. There will be a full report to Congress and to the Environmental Protection Agency by January the 1st of this year, a very long report which will summarize, of course, for you, which does state fairly categorically the quality of the data.

And we will then speculate on what the cause and effect is. So we will definitely tell you whether there has been a global change in ozone, both in the column and in the vertical distribution.

We will tell you the data quality. And then we will try and speculate whether we believe it is an indication of the fluorocarbons being more effective than we previously thought, or whether we believe it is natural variability.

Senator GORE. What is your gut feeling? I know scientists hate to be asked that.

Mr. WATSON. I have a very hard time believing that the fluorocarbons are five or 10 times more efficient than we previously thought.

Senator GORE. Yes.

Mr. WATSON. It would really mean the chemistry is very wrong. And I cannot see how it is that far off.

It would have meant, in my opinion, that many of the measurements we have taken of the general composition in the atmosphere do not make any sense.

So I believe it is probably a combination of just long-term natural variability, a decrease in solar activity since 1982, some funny effects of El Chichon in 1982, and the fluorocarbons.

Therefore, it may be very difficult to unravel the exact cause of the change since 1979.

Senator GORE. You say El Chichon, that was——

Dr. WATSON. Large volcanic activity.

Senator GORE. That volcano in Mexico.

Dr. WATSON. Correct.

Senator GORE. A very prolific volcano. Now, what is the optimum program for research that we ought to undertake in this country to resolve all of the uncertainties that we have been discussing today?

I want very brief responses, because I know when you ask the spokesmen for agencies involved in scientific research a question like that, you are inviting a long response. But what should our priorities be? And if you could make your responses brief I would appreciate it.

Dr. CORELL. I think all of us ought to speak to that question.

In setting priorities, NSF, and we in the Geosciences Directorate, have worked very closely with the science community—we have advisory committees, the National Academy of Sciences, and so forth—to try and first understand the science that is truly doable. We understand enough to place a high priority on addressing these global scale processes.

As you know, I am a recent addition to the Foundation, coming from the academic community. In am surprised at how much energy and effort goes into the priority-setting process within the Foundation, both in terms of the science itself, the state of science, its "doability," and its relationship to global questions such as the ones you are addressing in this hearing.

So we try to do that in a complex, sometimes difficult fashion. But I assure you that all these kinds of programs at the Foundation are set in a priority structure.

Furthermore, these two gentlemen here, and many others in the Foundation, are people with whom we talk on an almost daily basis so that we can try to search for that optimum.

I do think we will get an optimum science program. We certainly are working towards that as a goal, and it is a driving force in where we invest the taxpayers' money.

[The following information was subsequently received for the record:]

Those elements which constitute an optimum research program are still being established, and will evolve as a concept as we learn more and more about the effects of global environmental change. The National Academy of Sciences' Committee on Global Change, the forthcoming NASA report of Earth Systems Science, and the various agency long range plans will collectively contribute to defining a national effort in global change research.

There is no guarantee that we can, in fact, resolve all of the uncertainties related to a changing earth environment. But it is imperative that we begin those aspects of global change research that have already been recognized as having a dangerous impact on our planet.

To do this, the agencies are going ahead by planning for and funding those areas of earth sciences research that are the most timely, urgent, and imperative to un-

derstand, while at the same time coincident with our particular agency roles. For NSF that is our program in Global Geosciences which I briefly described for you. Careful thought went into the formulation of this program. The components represent the elements of global change research that the science community feels are the most essential to our understanding of planet earth. The emphasis on the linkages between scientific disciplines and the treatment of the earth as a system of processes is what makes the program unprecedented in its approach to environmental science. In Global Geosciences we have already funded and in some cases begun field work to define aspects of the earth system. This program in concert with related NSF and other-agency programs is already generating data bases required to address questions on such subjects as greenhouse gases, global warming, climate changes, and ozone depletion.

Senator GORE. Thank you. Dr. Fisk?

Dr. FISK. NASA, some years ago, as I mentioned in my testimony, put forth its Earth Systems Study Committee to essentially set out a planned program over the next 15 years. And that is one we are following.

It is essentially an evolutionary program. It uses existing proved missions, such as the upper atmosphere research satellite, which is really to make the premier measurements of the chemistry of the atmosphere, and essential for understanding the ozone problem.

And topex and scatterometer and so forth. And then build to what is the capability that will be available through the polar platform on the space station, to make essentially every conceivable coordinated measurement that we can make of the global environment.

We think the satellite technology is, along with the advances in computer technology, are essentially the new tools that allow you to address the earth on a global scale, and that NASA, using both tools, but in particular the techniques from satellites, will give us this perspective.

So we are building systematically towards that goal in the mid-1990s to the end of the century.

Senator GORE. Thank you. Dr. Hall?

Dr. HALL. Mr. Chairman, I will touch on two or three points very quickly.

First of all, the case has been made eloquently for a broad earth system research focus that must be sustained.

In the case of model development, however, we will have to move beyond simulating just the ocean atmosphere system by computer, to include the biosphere and other important interactions.

And I believe we have to move towards transition models. How do we get from one equilibrium state to the next? Many of the model results that you are seeing now, examine one equilibrium state, change that state arbitrarily, and compare the model results under the two conditions. The actual transitions are important; we must explore them.

Finally, I think that focused process research is necessary. I think it is inevitable that process research, the work on radiative gases, for example, will be driven in part by the societal problems that confronted us. Greenhouse warming and ozone depletion of course, are two of the very prominent ones.

In NOAA we have a single criterion that will determine our priorities: Where can we make the predictive inroads necessary to illuminate decisions?

Senator GORE. Very good. Well, while we are doing this research, Mr. Watson, you are part of the negotiating team over in Geneva. Is that correct?

Mr. WATSON. Correct.

Senator GORE. Is it your view that we ought to have a reduction in CFC production now?

Mr. WATSON. If you want to stabilize the ozone levels of the world, yes. I do. Correct.

Senator GORE. Well, there may be other questions in writing from the Chairman which I hope the agency witnesses will be willing to respond to in order to save time.

I appreciate all of you being a part of this hearing today. As I have said during the hearing, I believe the time for action is now. We must improve our database. We must have better research. But we must also begin acting responsibly now.

Thank you all very much for being a part of the hearing. We stand adjourned.

[Whereupon, at 12:20 p.m., the hearing was adjourned.]

[The following information was subsequently received for the record:]

STATEMENT OF HON. MAX BAUCUS, U.S. SENATOR FROM MONTANA

I am delighted to have the opportunity this morning to testify before this committee on global climate change. The greenhouse effect, global climate change, and stratospheric ozone depletion are interrelated environmental problems which pose the greatest environmental challenge that our planet will face in the next decade, and well into the next century.

I commend you, Mr. Chairman, for holding this hearing and for your continued interest in the greenhouse effect and global climate change. Since December of 1985, members of the Committee on Environment and Public Works have held eight days of hearings on these issues. We were pleased you participated in some of these hearings.

Testimony presented by earth and atmospheric scientists at these hearings presented a disturbing picture of the potential damage we may inflict on our planet by increasing the rate of emissions of carbon dioxide and other trace gases. Dr. Wallace Broecker described our actions in the following way:

> "The inhabitants of planet Earth are quietly conducting a gigantic environmental experiment. So vast and so sweeping will be its impact that, were it brought before any responsible council for approval, it would be firmly rejected as having potentially dangerous consequences. Yet the experiment goes on with no significant interference from any jurisdiction or nation."

The experiment in question is the so-called greenhouse effect - the release of carbon dioxide and other trace gases into the atmosphere. These gases trap infrared radiation emitted by the surface of the earth which would have otherwise escaped to space, causing our planet to heat up. An increase in the amount of greenhouse gases leads to an increase in the trapping of infrared radiation, and ultimately an increase in the temperature of our planet.

There is a need to focus the efforts of the scientific community on improving our understanding of the interrelated problems of the greenhouse effect, global climate change, and stratospheric ozone depletion. We need to set the "Greenhouse Effect" as the number one priority of the International Geosphere/Biosphere Program, and set priorities for our research efforts.

We are at a point in time where we must examine the policy options now. Some changes in climate are inevitable. The magnitude and timing of other changes are still speculative. We must ensure that the scientific research which is started today is designed to improve the information base to allow the Congress to make tough policy choices.

Research efforts need to be expanded. A coordinated broadly based approach is required. We must focus our efforts to answer questions such as:

1) What are the dynamics controlling large scale circulation of the ocean?

2) What are the processes regulating soil moisture?

3) What are the processes responsible for cloud formation?

4) What are the influence of global biogeochemical cycles on the atmosphere's composition?

5) What is the process regulating sea ice?

6) What are the mechanisms by which heterogeneous reactions may control the destruction of the ozone layer?

To help answer these questions we need supercomputers dedicated to providing improved modeling of cloud formation in the three dimensional atmospheric models, and for use in developing high-resolution coupling between ocean-atmosphere models.

There is also a critical need for a dedicated global climate observing system that, in addition to maintaining the existing monitoring systems, will incorporate a satellite based monitoring system with calibrated instruments to shed fundamental insights into how the climate system responds to external stimuli (such as trace gas increase) and how these stimuli are changing with time.

The role of the Commerce Committee in reviewing and directing the research programs of NASA, NOAA, and NSF will ensure that hard facts are available to support the policy decisions that will be needed.

The role of this Committee must be to set priorities and force a coordinated government-wide effort to provide the science before it is too late to do anything.

Let me review briefly where we are and what we know. Carbon dioxide concentrations have increased by 25% since 1900. Methane concentrations have risen about 100% in the last 150 years. In the last 35 years alone there has been a 30 to 40% increase. The two principal fluorocarbons implicated in the greenhouse effect - CFC-11 and CFC-12 - are growing at a rate of 5% per year. Nitrous oxide concentrations are growing at 2/10 of a percent per year. Tropospheric ozone is increasing by 1% per year in the Northern Hemisphere. Elsewhere on the globe, tropospheric ozone trends are not well known.

The excess radiation absorbed by these greenhouse gases provides the energy to drive the climate system and alter global and regional climate patterns, atmospheric circulation patterns, and oceanic circulation patterns.

What have scientists told us we can expect from this large scale experiment? The projected increases in the greenhouse gases are predicted to cause unprecedented global and regional climate changes.

Temperature will increase. Current models predict an increase in the average global temperature of 1.5 to 4.5 degrees centigrade by the year 2030. That is an increase of about 3 to 9 degrees Fahrenheit in only 40 years.

These "global average temperatures" do not accurately reflect local temperature changes. An average temperature rise of only three degrees centigrade could mean an increase of more than ten degrees centigrade at high altitudes in some seasons.

Precipitation will increase. A warmer climate will evaporate more moisture which will ultimately fall to the ground as precipitation. Hence, the globe will be wetter and more humid.

Precipitation patterns will change, possibly upsetting agricultural activities worldwide.

A warmer atmosphere will melt the sea ice in the polar regions. Since the underlying ocean is much darker than the sea ice, melting of the ice will lead to increased solar absorption. This absorption will act as a feed-back mechanism for further ocean and atmosphere circulation changes.

Current models predict that climate change will lead to the dessication of the continents in the mid-latitudes. In summer, the Great Plains of the United States, Central Europe, and parts of the Soviet Union could experience Dust Bowl conditions.

Sea level could rise from one to four feet, inundating our coastlines and contaminating drinking water supplies with salt water.

Ocean currents could shift, changing the climate of many areas and disrupting fisheries.

The frequency of tropical storms is predicted to increase, as is increased monsoonal rain in the tropics.

With the "greenhouse effect", we are not talking about short-term changes. We are talking about permanent and perhaps ongoing change for some indefinite period into the future.

Furthermore, we are not talking about localized areas being affected, but worldwide change. We will not be sure of the consequences of this experiment until the damage is done.

We are already committed to some of these changes. Past emissions of greenhouse gases have already committed Earth to warm by 0.5 to 1.5 degrees centigrade over the pre-industrial era. If emissions continue along their present track, we will have committed Earth to a warming of 1.5 to 4.5 degrees centigrade by 2030.

These changes may be occurring now. It is expected that within the next few years, we shall actually be able to measure these changes.

The fundamental issue that we face is to develop a strategy to deal with global climate change. The next decade should be a period of intense scientific research designed to provide answers to the greenhouse problem, policy exploration, and adoption of appropriate preventative and adaptive control measures.

There are things which we can do now. Increased efficiency in the use of fossil fuels, and energy conservation measures can reduce the concentrations of greenhouse gases.

Reductions in the emissions of chlorofluorocarbons will help to slow the rate of climate change, and will help to preserve the Earth's stratospheric ozone shield. A fifty percent reduction in the use of CFC's will reduce greenhouse gas emissions 10%. Both Senator Chafee and I have introduced legislation which would eventually phase-out the use of harmful man-made CFC's which are currently destroying the Earth's protective ozone layer. International negotiations seem to be moving forward.

The problem of global warming has reached a stage that requires a broader and more institutional commitment to international dialogue. The focus for this effort should be the United Nations Environment Program (UNEP). We need to urge UNEP to step forward with a comprehensive report on global climate change, detailing the seriousness of the problem for all nations of the world. This effort could play a pivotal role in developing an international committment to address this problem.

I look forward to working with you and this Committee to ensure that the United States is prepared to meet the challenge of global climate change. I am hopeful that discussions today with the program managers from NSF, NASA, and NOAA will lead to an understanding of where the United States research efforts on global climate change are headed.

I appreciate the opportunity to appear before you today to discuss the major environmental problem facing our planet, global climate change.

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COMMENTARY

Unpleasant surprises in the greenhouse?

Wallace S. Broecker

There is now clear evidence that changes in the Earth's climate may be sudden rather than gradual. It is time to put research into the build-up of carbon dioxide in the atmosphere on a better footing.

THE inhabitants of planet Earth are quietly conducting a gigantic environmental experiment. So vast and so sweeping will be the consequences that, were it brought before any responsible council for approval, it would be firmly rejected. Yet it goes on with little interference from any jurisdiction or nation. The experiment in question is the release of CO_2 and other so-called 'greenhouse gases' to the atmosphere. Because these releases are largely by-products of energy and food production, we have little choice but to let the experiment continue. We can perhaps slow its pace by eliminating frivolous production and by making more efficient use of energy from fossil fuels. But beyond this we can only prepare ourselves to cope with its effects.

The task of scientists is to predict the consequences of the build-up of CO_2 and other gases. To be useful these predictions must be reasonably detailed, but we are in no better a position to make them than are medical scientists when asked when and where cancer will strike a specific person. Understanding the operation of the joint hydrosphere – atmosphere – biosphere – cryosphere system is every bit as difficult as understanding the factors that determine whether or not cancerous cells will get the upper hand. Because of our lack of basic knowledge, the range of possibility for the greenhouse effects remains large. It is for this reason that the experiment is a dangerous one. We play Russian roulette with climate, hoping that the future will hold no unpleasant surprises. No one knows what lies in the active chamber of the gun, but I am less optimistic about its contents than many.

My suspicion is that we have been lulled into complacency by model simulations that suggest a gradual warming over a period of about 100 years. If this seemingly logical response to a gradual build-up of greenhouse gases is correct, then one can imagine that man may be able to cope with the coming changes. While I do not have any complaints about how these modelling experiments were conducted — indeed they were done by brilliant scientists using the best computers available — the basic architecture of the models denies the possibility of key interactions that occur in the real system. The reason is that we do not yet know how to incorporate such interactions into models.

My impressions are more than educated hunches. They come from viewing the results of experiments nature has conducted on her own. The results of the most recent of them are well portrayed in polar ice, in ocean sediment and in bog mucks. What these records indicate is that Earth's climate does not respond to forcing in a smooth and gradual way. Rather, it responds in sharp jumps which involve large-scale reorganization of Earth's system. If this reading of the natural record is correct, then we must consider the possibility that the main responses of the system to our provocation of the atmosphere will come in jumps whose timing and magnitude are unpredictable. Coping with this type of change is clearly a far more serious matter than coping with a gradual warming.

"We play Russian roulette with climate [and] no one knows what lies in the active chamber of the gun . . ."

For more than 100 years scientists have been aware that the Earth is in the midst of a series of cyclic glaciations. Oxygen isotope measurements made on microscopic shells from deep-sea sediments provide a continuous record of these events. They show that cycles averaging 100,000 years in length carried us from warm climates, comparable to today's, to the cold climates of full glacial time. Power spectra for these records point a finger at cycles in the Earth's orbital characteristics as the driving force[1,2]. Seasonality was at times stronger and at times weaker than it is today. Although most scientists now accept the orbital hypothesis, none of the mechanisms that have been proposed to explain the linkage between seasonality and climate is universally accepted. This matter is the subject of much research.

The $^{18}O/^{16}O$ record in deep-sea cores gives the impression that the response of the climatic system to orbital forcing is smooth and gradual (Fig. 1 — see over). Only recently have we begun to realize that this impression is a false one. One of the early clues came from studies of the ecology of the remains of planktonic organisms contained in deep-sea cores of rapidly accumulated sediment from the North Atlantic[3]. The ecological changes recorded in these cores probably reflect changes in surface-water temperature. This record does not show the gradual change scientists had become accustomed to. Instead it shows an abrupt end to glacial time and, even more interesting, a brief period of intense cold interrupting the warm period that followed (Fig. 1). Although the two records shown in Fig. 1 are quite different, they are not incompatible. Changes in $^{18}O/^{16}O$ in the shells of marine sediments are largely the result of the waxing and waning of the ^{18}O-deficient continental ice caps. As the response time of global ice caps is thousands of years, the ^{18}O record smooths out the rapid changes in climate.

It took more than this, however, to make us take these abrupt changes seriously. The evidence that turned our heads came from holes drilled through the Greenland ice cap. As a foot or so of ice forms from each year's snowfall, the record captures changes in the ice-cap environment no matter how rapid they have been. These changes are recorded in the ratio of isotopically 'heavy' to isotopically 'light' water in the ice (a measure of air temperature)[4,5], in the content of particulate matter in the ice (a measure of the dustiness of the air over the ice cap)[4] and in the content of CO_2 and other greenhouse gases contained in the air trapped as bubbles in the ice (a measure of the atmosphere's greenhouse capacity)[6]. Like the ecological record in deep-sea muds from the North Atlantic, the ice core records from Greenland give a dramatically different impression of the manner in which climate changes than do the oxygen isotope records for marine shells. They show that during glacial time climate changed frequently and in great leaps. The typical leap involves a 6°C change in air temperature, a fivefold change in atmospheric dust content and a 20% change in the CO_2 content of air. In cold times the air was dustier and contained less CO_2.

While the record in Greenland's ice shows that climate can change in big leaps, we have to look further for a clue as to why these leaps occur. The last of the events seen in the Greenland record is well documented not only in Greenland ice and in North Atlantic sediment, but also in lake and bog sediments from throughout Western Europe and maritime Canada[7]. On land it is recorded by large shifts in the ecology of plants (as recorded by their pollen grains). During warm periods trees grew in these areas; during cold periods

the trees were replaced by tundra shrubs. Although this last of the Greenland events is found in bog and lake sediments throughout northern Europe, it is not seen in similar records from the United States. This geographical distribution suggests the North Atlantic Ocean as the culprit. Based on this clue, we are beginning to see how devilish are the links between components of the climatic system.

Rather than responding smoothly to gradual forcing, the ocean–atmosphere system appears to respond by changing the way it works. India's climate provides an apt analogy. The winters in India are very dry because of the descent of cold air from the Tibetan plateau. Summer heating causes this atmospheric circulation pattern to reverse abruptly. Air rises from the Tibetan plateau, drawing oceanic air across the Indian subcontinent, and the dry conditions give way to monsoonal rains.

The Earth's climatic system currently works in a way beneficial to northern Europe[1]. This region is warmed by heat released from the surface waters of the North Atlantic. The amount is a staggering 30% of that received by the North Atlantic from the Sun! This heat is steadily carried northward, as on a conveyor belt, by the ocean circulation system. In the vicinity of Iceland the warm water meets cold air. The air warms and ameliorates climate on the adjacent land. The water cools, sinks to the abyss and flows as a great river, down the full length of the Atlantic, around Africa, through the southern Indian Ocean and finally up the Pacific Ocean (Fig. 2). This current carries 20 times more water than the world's rivers combined.

In the North Pacific the ocean conveyor belt runs just the other way round. Deep waters move towards the north and rise to the surface and then flow towards the Equator in the upper ocean. So in today's world, the Atlantic conveyor belt carries tropical heat for delivery to the atmosphere at high northern latitudes, while the Pacific conveyor belt forces cold surface waters to move southward, pushing the invading warm waters back towards the Equator.

Why does our ocean operate in this fashion? Although we don't have the complete answer, we do have the first principle. The circulation system is governed by salt. Because of the difference in the circulation patterns, surface waters in the North Atlantic are on average warmer than those in the North Pacific. This allows more water to evaporate from the North Atlantic than from the North Pacific, and in turn gives rise to a net transport of water vapour through the atmosphere from the Atlantic to the Pacific. The North Atlantic is enriched in salt by this process (and the North Pacific waters correspondingly diluted). The enrichment of salt in the North Atlantic must somehow be compensated by a flow of salt through the sea from Atlantic to Pacific. The compensation in today's ocean is achieved by the flow of a deep current of salty water from the Atlantic to the Pacific and a matching flow of correspondingly less salty water around the other way in the upper ocean.

The phenomenon that maintains this situation is, I suspect, a potentially dangerous one. The circulation pattern is self-reinforcing and hence self-stabilizing. The deep current is driven by the extra density supplied to the waters of the North Atlantic by the enrichment of salt. The enrichment of salt is driven by the heat carried by the warm water which flows northward in the upper Atlantic to supply the deep current. A classic chicken-and egg situation! Excess evaporation causes the deep current; the deep current causes excess evaporation.

What are the consequences of perturbation of this system? Palaeoclimatic evidence points to a shutdown of the North Atlantic conveyor belt during glacial periods. Such a shutdown would cool the North Atlantic and its adjacent lands by 6–8°C. This is turn would cause the boreal

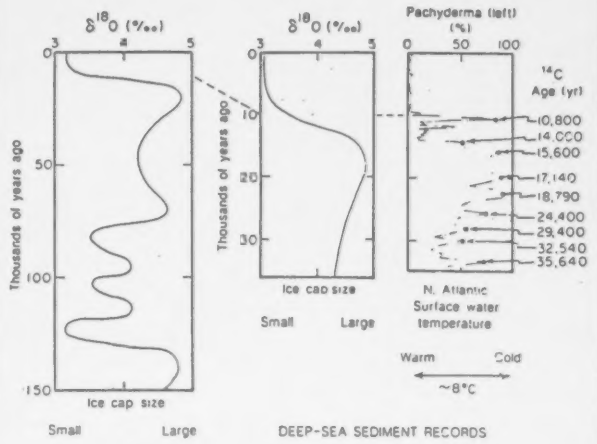

Fig. 1 The ratio of heavy oxygen (^{18}O) to light oxygen (^{16}O) in foraminifera shells preserved in deep-sea sediments provides our best record as to how the great continental ice sheets of the Northern Hemisphere waxed and waned. The reason is that the snow that builds ice caps is depleted in the heavy oxygen isotope. Therefore as ice caps grow, the ocean is correspondingly enriched in heavy oxygen. So also is the oxygen in the calcium carbonate of shells living in these waters.

The oxygen isotope record on the left covers just over one major climate cycle. There have been eight such cycles in the past million years. The diagram in the middle is an enlargement of that on the left, designed to emphasize that these oxygen isotope records indicate a gradual and smooth transition from full glacial to full interglacial conditions. Recent findings demonstrate that this view of natural climate change is misleading. The sluggish retreat of the ice and blurring of the record by burrowing worms combine to give what proves to be the wrong impression.

On the right is the record from a deep-sea sediment obtained west of the British Isles. This record is based on the abundance of the shells of the planktonic herbivore *Pachyderma* (left coiling) which lives in waters adjacent to Greenland. It is the only species of planktonic foraminifera found in these icy waters. During cold periods this species dominated the entire North Atlantic, providing up to 90% of the shells found in the sediments off Britain.

As can be seen, this record tells a different story. The North Atlantic warmed abruptly about 15,000 years ago, and has so remained (except for two brief cold relapses) until the present. It is the abruptness of the warming and of the two brief and intense epochs of renewed cold that are of great interest. The second of these cold epochs was first recognized from study of the pollen records in bogs created in northern Europe during the retreat of the last great ice sheet. These records show that the forests which repopulated this area after ice departed were destroyed by a brief and intensely cold interval of several hundred years' duration. They were replaced by the shrubs of glacial time.

forests in these areas to give way to tundra shrubs. The sparsity of vegetation would permit far more dust to be lifted into the atmosphere. Finally, the only feasible mechanisms scientists have come up with to explain rapid changes in the atmosphere's CO_2 content involve modifications in the ocean's circulation pattern and intensity. Thus we surmise that the reorganization of ocean circulation that accompanied the shutdown of deep-water production in the North Atlantic produced all of the environmental changes recorded in ice cores. The many leaps in climate seen in the glacial part of the Greenland ice core records probably represent flips of the system back and forth between two self-stabilizing modes of operation.

It must be emphasized that the leaps in climate seen in the ice and sediment records for the North Atlantic region were confined to the cold parts of the climatic cycle. Following the transition from cold to warm conditions 10,000 years ago, the climate in this region has remained remarkably constant. Apparently Earth's climatic system has remained firmly locked in its present mode of operation. If so, what is the likelihood that increases in CO_2 and other greenhouse gases will jolt the ocean–atmosphere system out of its current mode into one more suitable to the coming conditions?

Unfortunately, we have little basis for answering this critical question. Nature provides us with no recent analogy to the super-interglacial conditions we are about to generate. The climate of the past 10,000 years is representative of the warmest part of the last several glacial cycles. Hence nature has not explored the super-interglacial climatic regime (at least not in sufficiently recent times that our geological records give an adequate picture of Earth's environment to be useful for future prediction). Further, as we have only recently become aware of the complexity of the linkages which tie together ocean, atmosphere, ice and terrestrial vegetation, we have not even begun to formulate means by which these linkages might be modelled. Indeed, reliable modelling may never be possible.

If we are to get into a position to cope with the effects not only of the greenhouse gases, but also of the various poisons being released to the environment, we must greatly expand our efforts to understand the individual parts of the Earth's great surface system and the interactions among them. The task, however, is every bit as complex as that of preventing cancer.

I see no hope of getting much done in the United States without a fundamental reorganization of our approach to environmental research. I believe that most scientists would agree that the handling of research on greenhouse effects by the Department of Energy and on acid rain by the Environmental Protection Agency has been ineffective. The problem lies partly in the perception by the managers of these programmes that their mandate is to obtain quick fixes, and partly in their inability to grasp the subtleties of the problems placed under their jurisdiction. The result is that these managers avoid long-term strategies designed to build up our base of knowledge. Rather, they are strongly attracted by proposals to re-work existing information even though most scientists agree that it has been squeezed nearly dry. Thus, while the existing programmes serve to keep management informed, they do little to further our ability to predict the consequences of our actions. It is as if the efforts to prevent cancer were based largely on epidemiological information with no biochemical or cellular research. If we are to get out of this rut, the responsibility for basic research on environmental systems must be wrested from these mission-orientated agencies and given instead to an organization which is dedicated to basic research and is isolated from immediate political pressures.

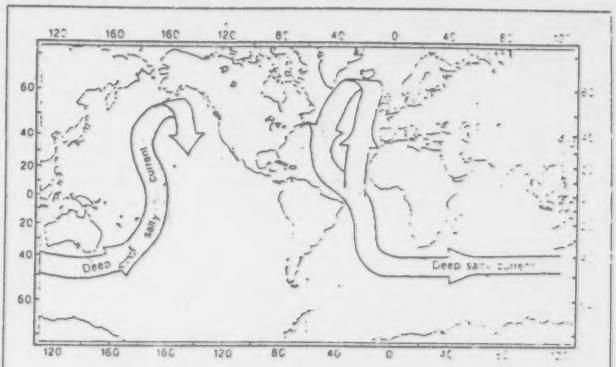

Fig. 2 A large-scale salt transport system operates in today's ocean to compensate for the transport of water (as vapour) through the atmosphere from the Atlantic to the Pacific Ocean. Salty, deep water formed in the North Atlantic flows down the length of the Atlantic, around Africa, through the southern Indian Ocean and finally northward in the deep Pacific Ocean. Some of this water upwells in the North Pacific, bringing with it the salt left behind in the Atlantic due to vapour transport. This atmospheric water vapour and ocean salt transport system is self-stabilizing. Records from ice and sediment tell us that this great conveyor system was somehow disrupted during glacial time and replaced by an alternative mode of operation.

As it now stands, a healthy component of basic research is being carried out only in those areas where there is a strong tradition of federal sponsorship (that is, the atmospheric and ocean sciences). Research on the continental parts of the environmental system (vegetation, soils and waters) remains in the Dark Ages. It's a Catch-22 situation — managers at the National Science Foundation (NSF) feel that basic research in these areas should be sponsored by the appropriate mission-orientated agency, but such agencies shun basic research.

Unique opportunities to expand our knowledge of environmental systems slip by without being fully exploited. A prime example is the invasion of man-made tracers (that is, nuclear-testing tritium and radiocarbon, reactor radiokrypton and industrial freons) into the sea. A detailed knowledge of the patterns and rates of movement of these substance through the sea will prove a tremendous boon to the validation of general circulation models for the atmosphere–ocean system. Although the atmospheric side of such models is fully developed, the oceanic side is still in a primitive state. Further development is hampered by our lack of knowledge of the physics of key processes occurring in the sea. Because of this, ocean models of adequate sophistication are decades away. Despite the obvious value of tracer data, the efforts to map the passage of these substances through the sea's interior are sparse. NSF is concerned that surveying brings too little immediate scientific yield, while the mission-orientated agencies fail to appreciate the fact that if we are to understand the Earth's system we must adopt long-term strategies. With the exception of the French, who have developed a remarkably good tracer programme in the Indian Ocean, other industrial countries have shown no greater interest in ocean tracers than had the United States. Hence future ocean modellers will rue the deficiencies in the documentation of man's great ocean-tracer experiment.

I am not suggesting that things could

be altered simply by increasing NSF's budget. NSF is not set up to put strings on the use of its funds. Nor should it be. But to do the kind of research that will be required if we are to deal effectively with long-term environmental problems, there must be some strings.

In this time of budget deficits it may be unrealistic to call for new government entities, but I am convinced that the only way to straighten out the mess in environmental research is to create a new national institute. This institute would have two objectives. First, it would sponsor environmental research; second, it would advise the government on a broad range of environmental questions.

The International Committee of Scientific Unions has recently given its blessing to a new initiative in environmental science, the International Geosphere–Biosphere Program (IGBP). The aim is to further our understanding of the operation of the individual elements of the environmental system and of the linkages between them. The mission-orientated agencies in the United States are already planning how to capture their share of this new pie. Judging by past performance, it would be a mistake to let them have any of it. Instead, the US monies to be spent on IGBP should be funnelled through a new entity, The National Institute for the Environment. The primary responsibility of this institute would be to develop integrated programmes dedicated to furthering our knowledge of environmental systems. In particular, the Institute would focus on those areas that most need attention, namely, the continental components of the climatic system. The programmes would be planned by the most capable scientists in the country and conducted in the most appropriate laboratories (university, industry and government). The institute would be overseen by a board of trustees, consisting of eminent scientists. Its director, chosen by this board, would be a highly capable scientist, skilled in management. While the institute would have its own in-house scientific staff, most of its resources would go towards the funding of external activities.

There are isolated success stories. For example, two NASA managers, Shelby Tilford and Bob Watson, are running a programme designed to determine the sources of atmospheric methane and how the strengths of these sources have changed with time. This programme is a beautiful example of how environmental research should be conducted. It was designed by the nation's most knowledgeable scientists and is being carried out by highly capable groups throughout the country. The cost is modest, about two million dollars a year, and the payoff will be large. It works because Watson and Tilford are themselves outstanding scientists who know what the tractable problems are and where the intellectual resources to tackle them reside.

Most of the research of the new institute should be housed in universities. It is in such settings that excellent research is generated for a minimum cost. By placing graduate education and research under one roof, an optimum environment for both is created. With a few exceptions, environmental research in large laboratories operated by government agencies has, in my opinion, proved to be unproductive and wasteful.

There are, however, two tasks that clearly require facilities not available to universities. One involves satellite observations, which will be the cornerstone of the effort to monitor the climatic system. Such platforms are best operated by NASA. The other is large-scale climate modelling, which is now the basis for all climate prediction. These facilities require large research staffs and immense computer power. Fortunately, a successful format has already been found which involves cooperation between universities and government departments. The National Oceanic and Atmospheric Administration has its primary effort on Princeton's campus. NASA bases such an effort on Columbia's campus. NSF operates such an effort at its National Center for Atmospheric Research in Boulder, Colorado. Because of the great importance of the so-called 'general circulation models' to climate prediction, these existing laboratories should be strengthened. Also, similar efforts must be launched in other university settings.

"Not only do our current managers lack a proper intellectual grasp of the problem, but they are obsessed with legislatively imposed 'five-year reports', and give little attention to developing a long-term strategy to build the needed base of knowledge."

Five specific areas in which research must be greatly expanded can be singled out for special attention: (1) the large-scale circulation of the ocean; (2) the processes regulating soil moisture; (3) the processes responsible for cloud formation; (4) the role of biogeochemical processes on the atmosphere's composition; (5) the processes regulating sea ice.

Of course, there are already research programmes in these areas, but in my estimation they will not come up with answers quickly enough. In each area we need major new observational programmes to supply the key data that are necessary to develop a better physical understanding. In each area we need a cadre of young scientists with the appropriate training.

We also have to intensify our study of the climatic changes that have taken place over the past 100,000 years. As discussed above, nature herself has conducted large-scale climatic experiments. The response of the system to these natural experiments is recorded in sediments and in ice. By study of these records, we will be able to learn valuable lessons about the interactions that link the various elements of Earth's system together. I should stress once again that it is changes in these linkages which are likely to carry the greatest threats.

Although we don't know nearly enough about the operation of the Earth's climate to make reliable predictions of the consequences of the build-up of greenhouse gases, we do know enough to say that the effects are potentially quite serious. Whatever happens, it seems to me that the Earth's remaining wildlife will be dealt a serious blow. If, as the climatic record in ice and sediment suggests, changes in climate come in leaps rather than gradually, then the greenhouse build-up may threaten our food supply. To date, we have dealt with this problem as if its effects would come in the distant future and so gradually that we could easily cope with them. This is certainly a possibility, but I believe that there is an equal possibility that they will arrive suddenly and dramatically.

To prepare ourselves, we must take the problem of climatic change as seriously as we take those of cancer and nuclear defence. There are no easy solutions, and we must gear up for the long, hard job of working out how Earth's climate operates. To do this will require not only more financial and human resources, but also the administration appropriate to the task. Not only do our current managers lack a proper intellectual grasp of the problem, but they are obsessed with legislatively imposed 'five-year reports', and give little attention to developing a long-term strategy to build the needed base of knowledge. Even with a great intensification of effort, I fear that the effects of the rise in concentration of the greenhouse gases will come largely as surprises. But the greater our knowledge, the greater the wisdom that will be brought to bear if surprises do come. □

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